OUR CHANGING PLANET

The U.S. Climate Change Science Program for Fiscal Year 2008

A Report by the
Climate Change Science Program and
the Subcommittee on Global Change Research

A Supplement to the President's Budget for Fiscal Year 2008

OUR CHANGING PLANET

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Climate Change Science Program and Subcommittee on Global Change Research

William J. Brennan
Department of Commerce
National Oceanic and Atmospheric Administration
Acting Director, Climate Change Science Program; and Chair, Subcommittee on Global Change Research

Jack Kaye, Vice Chair
National Aeronautics and Space Administration

Thomas Armstrong
U.S. Geological Survey

Allen Dearry
Department of Health and Human Services

Jerry Elwood
Department of Energy

Mary Glackin
Department of Commerce

Patricia Gruber
Department of Defense

William Hohenstein
Department of Agriculture

Linda Lawson
Department of Transportation

Jarvis Moyers
National Science Foundation

Patrick Neale
Smithsonian Institution

Jacqueline Schafer
U.S. Agency for International Development

Joel Scheraga
Environmental Protection Agency

Harlan Watson
Department of State

Executive Office and Other Liaisons

George Banks
Council on Environmental Quality

Melissa Brandt
Office of Management and Budget

Stephen Eule
Department of Energy
Director, Climate Change Technology Program

Howard Frumkin
Centers for Disease Control and Prevention

Katharine Gebbie
National Institute of Standards and Technology

Margaret R. McCalla
Office of the Federal Coordinator for Meteorology

Gene Whitney
Office of Science and Technology Policy

This document describes the U.S. Climate Change Science Program (CCSP) for FY 2008. It provides a summary of the achievements of the program, an analysis of the progress made, and budgetary information. It thereby responds to the annual reporting requirements of the U.S. Global Change Research Act of 1990 (Section 102, P. L. 101-606). It does not express any regulatory policies of the United States or any of its agencies, or make any findings of fact that could serve as predicates for regulatory action. Agencies must comply with required statutory and regulatory processes before they could rely on any statements in this document or by the CCSP as a basis for regulatory action.

OUR CHANGING PLANET

The U.S. Climate Change Science Program for Fiscal Year 2008

A Report by
the Climate Change Science Program and
the Subcommittee on Global Change Research

A Supplement to the President's Budget for Fiscal Year 2008

October 2007

Members of Congress:

We are pleased to transmit a copy of *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2008*. The report describes the activities and plans of the Climate Change Science Program (CCSP), which incorporates the U.S. Global Change Research Program, established under the Global Change Research Act of 1990, and the Climate Change Research Initiative, established by the President in 2001. CCSP coordinates and integrates scientific research on climate and global change supported by 13 participating departments and agencies of the U.S. Government.

This Fiscal Year 2008 edition of *Our Changing Planet* highlights recent advances and progress supported by CCSP-participating agencies in each of the program's research and observational elements, as called for in the *Strategic Plan for the U.S. Climate Change Science Program* released in July 2003.

The document describes a wide range of advances in understanding the underlying processes responsible for climate variability and change, such as advances in understanding of climate change at high latitudes. It also describes progress on understanding the ongoing and projected effects of climate change on nature and society, including the interconnected relationships between climate, forests, and wildfire. The document also describes how observational and predictive capabilities are being improved and used to create tools to support decisionmaking at local, regional, and national scales to cope with environmental variability and change.

The document outlines how CCSP plans to continue implementation of the *Strategic Plan* during FY 2008. The program will continue to emphasize work on 21 scientific synthesis and assessment products, three of which have been completed. Two of these products were released in the past year. The first, entitled *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application*, used computer-based models to assess the economic and technological implications of limiting greenhouse gas emissions. This product also described key principles underlying the development of global change scenarios. The second, entitled *Effects of Climate Change on Energy Production and Use in the United States*, summarized current understanding on how climate change could affect energy production, supply, and consumption in the United States. The remaining products are well underway.

CCSP is committed to its mission to facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication. We thank the CCSP-participating agencies for their close cooperation, and we look forward to working with Congress in the continued development of this important program.

Samuel W. Bodman

Secretary of Energy

Chair, Committee on
Climate Change Science and
Technology Integration

Carlos M. Gutierrez

Secretary of Commerce

Vice Chair, Committee on
Climate Change Science and
Technology Integration

John H. Marburger III

Director, Office of Science
and Technology Policy

Executive Director,
Committee on
Climate Change Science and
Technology Integration

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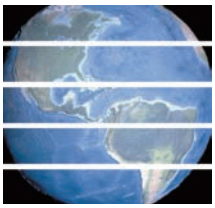


THE U.S. CLIMATE CHANGE SCIENCE PROGRAM FOR FY 2008

Climate plays an important role in shaping the environment, natural resources, infrastructure, economy, and other aspects of life in all countries of the world. Therefore, variations and changes in climate can have substantial environmental and socioeconomic implications. The Climate Change Science Program (CCSP) was established in 2002 to empower the Nation and the global community with the science-based knowledge to manage risks and opportunities of change in the climate and related environmental systems. CCSP incorporates and integrates the U.S. Global Change Research Program (USGCRP) with the Administration's U.S. Climate Change Research Initiative (CCRI). The USGCRP was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606, 104 Stat. 3096-3104) to improve understanding of uncertainties in climate science, expand global observing systems, develop science-based resources to support policymaking and resource management, and communicate findings broadly among scientific and stakeholder communities.

Climate research conducted over the past several years indicates that most of the global warming experienced in the past few decades is very likely due to the observed increase in greenhouse gas concentrations from human activities. Research also indicates that the human influence on the climate system is expected to increase.[1] It is therefore essential for society to be equipped with the best possible knowledge of climate variability and change so that we may exercise responsible stewardship for the environment, lessen the potential for negative climate impacts, and take advantage of opportunities where they exist. The importance of these issues and the unique role that science can play in informing society's responses give rise to CCSP's guiding vision.

CCSP GUIDING VISION

A nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems.

CCSP carries out its mission through four core approaches: scientific research, observations, decision support, and communication. These approaches build upon scientific advances of the last few decades and are deepening understanding of the interplay of natural and human-caused forces, their implications, and response options. CCSP is developing information to facilitate comparative analysis of different approaches for adapting to and mitigating climate change. CCSP also promotes capacity development among scientists and information users—both in the developed and the developing world—to address the interactions between climate change, society, and the environment.

CCSP MISSION

Facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication.

Integrating Climate and Global Change Research

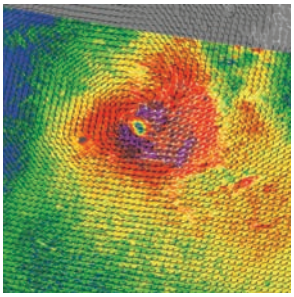
Thirteen departments and agencies of the U.S. Government participate in CCSP, including:

- Department of Agriculture (USDA)
- Department of Commerce (DOC)
  - National Oceanic and Atmospheric Administration (NOAA)
  - National Institute of Standards and Technology (NIST)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior (DOI)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

In addition, the Executive Office of the President and other related programs have designated liaisons who participate on the CCSP Interagency Committee, including:

- Office of Science and Technology Policy (OSTP)
- Council on Environmental Quality (CEQ)

- Office of Management and Budget (OMB)
- Climate Change Technology Program (CCTP)
- Centers for Disease Control and Prevention (CDC)
- Office of the Federal Coordinator for Meteorology (OFCM).



Appendix A, "The Climate Change Science Program Participating Agencies," contains information about the specific missions and roles of each agency participating in the program. Appendix B, "Climate Change Science Program FY 2008 Budget Tables," contains budgetary analyses of the program grouped by agency as well as a program-wide interagency cross-cut grouped by the strategic goals and research elements of CCSP, as described in the *Strategic Plan for the U.S. Climate Change Research Program* published in July 2003.

CCSP is responsible for coordinating and integrating scientific research on global environmental variability and change sponsored by these agencies to take advantage of their unique approaches and missions, and to encourage research that leads to expanded and new results. Thus, the program helps to catalyze research that goes beyond individual agency missions to address overarching national objectives and to achieve results that no single agency, or small group of agencies, could attain. A significant challenge that arises from working across many agencies is integrating climate and global change research to develop a comprehensive view of climate change and its potential significance.

CCSP relies not only on the agency programs stated in its budget cross-cut, but also on agency activities that are not formally included in the CCSP budget. Examples of these directly related activities are surface hydrologic and satellite land-cover observations from the U.S. Geological Survey (USGS), and future satellite measurement programs including portions of the tri-agency (NOAA/DOD/NASA) National Polar-Orbiting Operational Environmental Satellite System (NPOESS) and the planned implementation of a Landsat data continuity mission.[a] Without input from activities such as these, CCSP would be unable to fulfill its mission.

CCSP is closely allied with other major interagency programs that observe and study particular aspects of the Earth system and related societal dimensions. Foremost among these is the CCTP, which develops and studies technological options for responding to climate change. CCSP is also closely linked to ongoing Federal ocean science and technology strategic planning under the auspices of the Joint

[a] As a result of the recent review and reformulation of its CCSP contributions, NASA considers 33% of its Landsat Data Continuity Mission (LDCM) budget and 100% of its National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project budget to contribute to CCSP. NASA budget figures provided in this report reflect the inclusion of this funding.

DEFINITION OF KEY TERMS

Adaptation
Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

Climate
The statistical description of the mean and variability of relevant measures of the atmosphere-ocean system over periods of time ranging from weeks to thousands or millions of years.

Climate Change
A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing, including changes in solar radiation and volcanic eruptions, or persistent human-induced changes in atmospheric composition or in land use.

Climate Feedback
An interaction among processes in the climate system in which a change in one process triggers a secondary process that influences the first one. A positive feedback intensifies the change in the original process, and a negative feedback reduces it.

Climate Forcing
A process that directly changes the average energy balance of the Earth-atmosphere system by affecting the balance between incoming solar radiation and outgoing or "back" radiation. A positive forcing tends to warm the surface of the Earth and a negative forcing tends to cool the surface.

Climate System
The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface, the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and human-induced forcings such as the changing composition of the atmosphere and land-use change.

Climate Variability
Variations in the mean state and other statistics of climatic features on temporal and spatial scales beyond those of individual weather events. These often are due to internal processes within the climate system. Examples of cyclical forms of climate variability include the El Niño Southern Oscillation, the North Atlantic Oscillation, and the Pacific Decadal Oscillation.

Decision-Support Resources
The set of observations, analyses, interdisciplinary research products, communication mechanisms, and operational services that provide timely and useful information to address questions confronting policymakers, resource managers, and other users.

Global Change
Changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life (from the Global Change Research Act of 1990, PL 101-606).

Mitigation
An intervention to reduce the human-induced factors that contribute to climate change. This could include approaches devised to reduce emissions of greenhouse gases to the atmosphere; to enhance their removal from the atmosphere through storage in geological formations, soils, biomass, or the ocean; or to alter incoming solar radiation through several "geo-engineering" options.

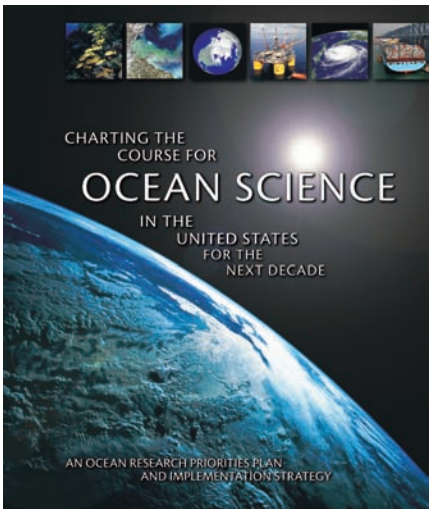
Observations
Standardized measurements (either continuing or episodic) of variables in climate and related systems.

Prediction
A probabilistic description or forecast of a future climate outcome based on observations of past and current climatological conditions and quantitative models of climate processes (e.g., a prediction of an El Niño event).

Projection
A description of the response of the climate system to an assumed level of future radiative forcing. Changes in radiative forcing may be due to either natural sources (e.g., volcanic emissions) or human-induced factors (e.g., emissions of greenhouse gases and aerosols, or changes in land use and land cover). Climate "projections" are distinguished from climate "predictions" in order to emphasize that climate projections depend on scenarios of future socioeconomic, technological, and policy developments that may or may not be realized.

Weather
The specific condition of the atmosphere at a particular place and time, measured in terms of variables such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

Subcommittee on Ocean Science and Technology (JSOST), which recently released a set of integrating decadal-scale national research priorities in key areas of interaction between society and the ocean.[2] A key observational linkage is with the U.S. Integrated Earth Observation System, which is part of the international Global Earth Observation System of Systems (GEOSS). Connections to programs such as these allow CCSP and its partners to leverage their resources to derive mutual benefits from advances in any one program.

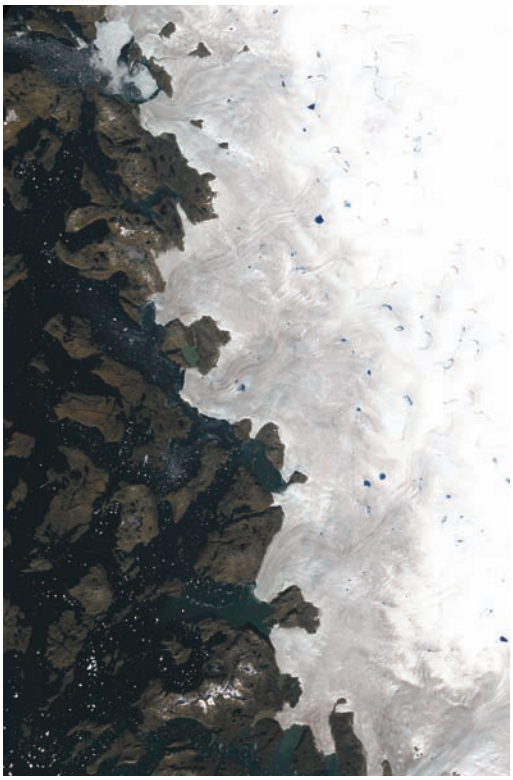


Program Management

CCSP's coordination of scientific research is accomplished through the research elements described in the following section. The management approach as described in the *CCSP Strategic Plan* integrates the planning and implementation of individual climate and global change research programs of the participating Federal agencies and departments to reduce overlaps, identify and fill programmatic gaps, and synthesize products and deliverables generated under the auspices of CCSP. Five mechanisms are used to achieve this management approach:

- *Executive Direction* – The Interagency Working Group on Climate Change Science and Technology and the CCSP Interagency Committee are responsible for overall priority setting, program direction, management review, and accountability to deliver program goals.
- *Agency Implementation* – CCSP participating departments and agencies are responsible for conducting research, developing modeling tools, developing and operating observing systems, and producing CCSP-required products, often in collaboration with interagency working groups.
- *Interagency Planning and Implementation* – Several interagency working groups, including one for each CCSP research element, are responsible for coordinating planning and implementation to align agency programs with CCSP priorities.
- *External Guidance and Interaction* – External advisory groups and organizations, including the National Academies, provide external guidance, oversight, and interactions to ensure scientific excellence, credibility, and utility.
- *Program Support* – The CCSP Office provides staffing and day-to-day coordination of CCSP-wide program integration, strategic planning, product development, and communications.

Coordinating Research Elements



Efforts to foster integration occur on many levels. One is improving coordination of scientific research and the flow of information through interdisciplinary and interagency working groups focused on each of seven main research elements of the program plus a number of cross-cutting activities or themes. CCSP's research elements include atmospheric composition, climate variability and change, the global water cycle, land-use and land-cover change, the global carbon cycle, ecosystems, and human contributions and responses to environmental change. Chapters 3 to 15 of the *CCSP Strategic Plan* contain more detailed discussions of the discipline-specific research elements, as well as elements that cut across all areas of the program. A brief summary of each of these research and cross-cutting elements is provided in this document, as well as highlights of planned activities.

Integrating research and observational approaches across disciplinary boundaries is essential for understanding how the Earth system functions and how it will change in response to future forcing. This is due to the interconnectedness among components of the Earth system, which often relate to each other through feedback loops. Interdisciplinary interactions in CCSP are scaled to the nature of the problem. In some cases, the necessary science may be conducted within a small set of disciplines, such as those required to improve understanding of soil biogeochemical processes. In other cases, highly interdisciplinary and multi-scale approaches are required, such as in the case of making projections about the future state of the Earth system and analyzing their implications. In this case, expertise ranging from the social sciences to atmospheric dynamics and chemistry to oceanography to the biological sciences is required. Examples of interdisciplinary research are the coordinated planning and operation of two field campaigns in the southern Great Plains in 2007 examining the effects of land-surface processes and aerosols on cumulus clouds (see <science.arm.gov/clasic> and <asp.labworks.org>). These campaigns, involving several different agencies, were designed to address interdisciplinary science questions spanning three CCSP research elements: global water cycle, atmospheric composition, and global carbon cycle.

Interdisciplinary research is only one aspect of the integration facilitated by CCSP. Integration in CCSP also refers to the steps being taken to create more seamless approaches between the theory, modeling, observations, and applications that are required to address the multiple scientific challenges being confronted by CCSP. Finally, integration in CCSP also refers to the enhancement of cooperation across agencies toward meeting the objectives articulated in the *CCSP Strategic Plan*.

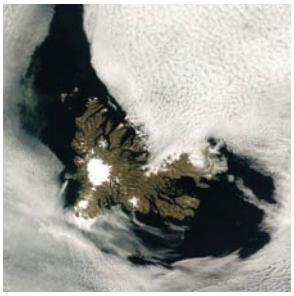
Integrated Program Analysis

In a highly distributed program such as CCSP, it is often a challenge to develop and maintain a cohesive perspective, ensuring that key components or interactions of the integrated Earth system are not overlooked. To help address this challenge, the program has often sought guidance from the National Academies. CCSP is funding a National Research Council (NRC) committee to provide high-level, independent, integrated advice on the strategy and evolution of the program. Specific topics the committee will address in its first two reports are outlined below.

- The first committee report (released in September 2007) included findings and recommendations on the process for evaluating progress toward the five CCSP goals and a preliminary assessment of progress to date.
- The second report will identify priorities to guide the future evolution of the program in the context of established scientific and societal objectives.

At the request of CCSP, the NRC recently produced a report on global change assessments that is briefly described in a later section.

CCSP will continue to rely on other mechanisms for scientific guidance and advice, including other NRC committees that focus on particular components of the climate system (e.g., the Climate Research Committee and the Committee on the Human Dimensions of Global Change). CCSP will continue to rely on scientific advisory groups that support individual agencies, scientific steering groups organized to coordinate different CCSP research elements, and open dialog with the domestic and international scientific and user communities interested in global change issues.



CCSP Goals and Analysis of Progress Toward These Goals

At the highest conceptual level, five goals have been identified to provide focus and facilitate programmatic integration (see accompanying box). These goals encompass the full range of climate-related issues. The program's detailed objectives, milestones, products and payoffs complement these overarching goals, and are articulated in the program's *Strategic Plan*. CCSP-participating agencies and departments coordinate their work through discipline-related "research elements," which together support scientific research across a wide range of interconnected issues of climate and global change. The goals address the most common questions concerning climate change, which include:

- To what extent and how is the climate system changing?
- What are the causes of these changes?
- What will the future climate be like and what effects will a changed climate have on ecosystems, society, and the economy?

CCSP GOALS

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

- How can we best apply knowledge about ongoing and projected changes to decisionmaking?

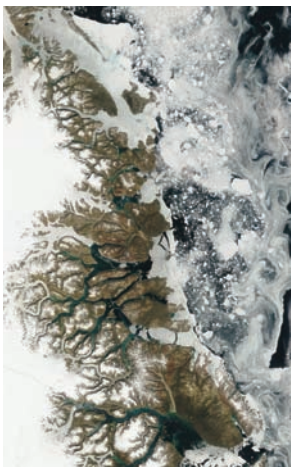
This section provides a high-level overview of progress made toward the program's goals in the 12 to 18 months prior to the preparation of this report. Because of the program's breadth and wide-ranging progress, this overview gives only a sampling of the advances made. In addition, this section does not purport to provide a thorough assessment of climate change or the extent of the scientific uncertainties that remain. Instead, it provides examples that illustrate the scope and significance of the progress that CCSP has made in expanding and applying understanding of climate.

The primary focus of U.S. climate research has historically been on Goals 1 through 3, which emphasize improvements in fundamental understanding of the climate system, its driving forces, and the tools to make predictions of short-term climate variability and potential long-term climate change more reliable. As the science matures and its societal utility becomes more evident, the importance of Goals 4 and 5 has become more significant. Examples of progress provided under each of the goals are often the result of coordinated research activities from many disciplines conducted or supported across the participating CCSP agencies.

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Analyses based on observations provide a solid foundation for the program. These analyses contribute to improved understanding of Earth system processes, help determine the extent of climate variations, and provide objective comparisons to test and advance model veracity. In the past year, analyses have enabled several important

advances in understanding the nature and variability of the Earth system. The illustrative examples below of progress toward CCSP's Goal 1 are drawn from and integrate a variety of different CCSP research elements.

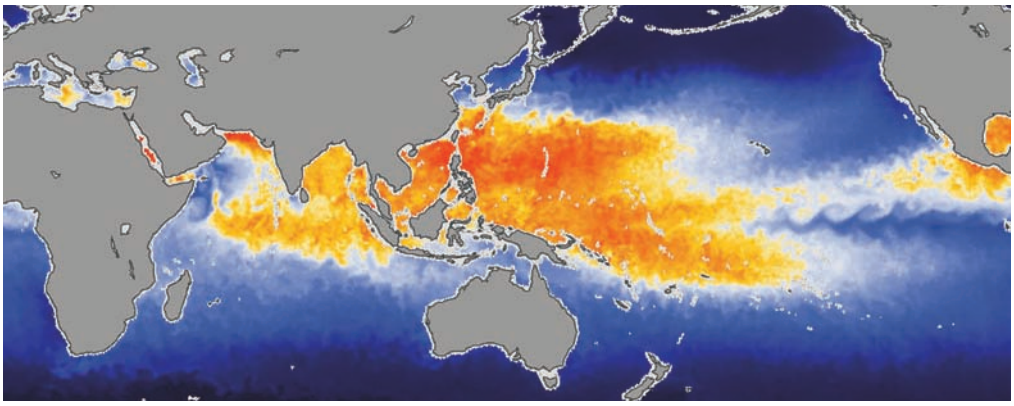


One example of these integrated analyses is the progress made in understanding climate change at high latitudes. Temperature and moisture patterns over North America and Europe are experiencing an earlier transition from winter to summer. The warmer spring temperatures produce earlier spring green-up of vegetation and longer growing seasons.[3] Satellite, airborne, and ground-based observations suggest that significant changes are occurring in the mass balance of the Greenland and Antarctic Ice Sheets that are inferred to be caused by warming at high latitudes.[4,5] Analyses of observations and climate model simulations suggest that the pattern of high latitude temperature change is more readily explained by estimated human activity and natural climate forcing than by internal variability alone.[b] These wide-ranging sets of analyses tie together findings from traditionally disparate disciplines including hydrology, glaciology, and ecology.

Two recent studies demonstrate progress made in improved understanding of climate influences on ozone distribution. Using satellite measurements corroborated by surface measurements, one study found increases in ozone in the Antarctic middle stratosphere during southern hemisphere summer (December). Model simulations showed that these increases were caused by the delayed transition from dynamic springtime conditions to more stable summer conditions due to the springtime ozone hole. The continuation of springtime dynamics forces descent of ozone-rich air from higher levels of the atmosphere to the lower, mid-stratosphere (about 30-km altitude). This study also found that future greenhouse gas increases would produce similar ozone increases.[6] The second study found that doubling of carbon dioxide (CO_2) caused a strengthening of the circulation responsible for the global distribution of ozone. The results of this study reveal that total ozone will increase at high latitudes of the Northern and Southern Hemispheres, and decrease in the Tropics.[7]

In the past decade, measurements from a variety of platforms, including satellites and ocean buoys, show warming in the top layers of the ocean, with strong evidence that the warming is due to increases in human-produced greenhouse gases.[1] Ocean heat storage is the largest component of the Earth's climate system for storing the energy imbalance between the sources and sinks of thermal energy. Even though the methods of observations are quite different, the matching magnitude and annual variability of

[b] Climate forcing is a process that directly changes the average energy balance of the Earth-atmosphere system by affecting the balance between incoming solar radiation and outgoing or "back" radiation.



the satellite-derived energy imbalance and the ocean heat storage is considered to be quite remarkable and lends confidence to the interpretation of the underlying climate process.[8]

The basic research conducted in CCSP Goal 1 is directly relevant to society. An example is work on identifying relationships between hurricane activity and climate variability and change. Theoretical and modeling studies suggest that increasing tropical sea surface temperatures are likely to be associated with more intense, but not necessarily more frequent, hurricanes.[9] Over the North Atlantic Ocean, there is strong observational evidence for an increase in intense tropical cyclone activity since 1970 that is correlated with increasing sea surface temperatures.[10] However, in basins other than the North Atlantic, trends in tropical cyclone activity have varied considerably during this period, although most basins have also experienced warming sea surface temperatures.[11] In the Atlantic and Pacific tropical cyclone genesis regions, the sea surface temperature changes appear to be due to a combination of natural variations and anthropogenic forcing.[12] Aside from differences between basins, results of tropical cyclone trend calculations appear sensitive to the length of the observational record and the techniques used to identify and characterize hurricanes. Consequently, considerable debate remains over present abilities to detect global trends in tropical cyclone activity.[13]

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

In making long-term climate projections, an understanding of the factors responsible for global environmental change is necessary. These forcing factors include greenhouse gases, land-cover changes, tiny airborne particles (aerosols), and solar variability. As in the previous goal, the following examples of progress toward CCSP Goal 2 result from the integrated focus of multiple CCSP research elements.

Recent climate warming has been particularly intense in boreal and Arctic regions, leading to concern that increasing air temperature in these ecosystems may indirectly increase the incidence of forest fires. Beyond the emission of CO_2 and other greenhouse gases, understanding the consequences of large-scale fires for climate is challenging due to the many additional ways in which they influence the atmosphere and surface. A recent study in Alaska found that there was intensification in the climate warming in the first year after a major fire but a slight decrease in the local climate warming when averaged over the 80 years of the study. The long-term result, which was primarily due to plant regrowth increasing the summer reflectivity of the burned surface, appeared to be more significant than the fire-emitted greenhouse gases.[14] The result suggests that future increases in wildfire in some parts of the boreal zone of Alaska may have different feedbacks to global warming than previously thought.

CCSP's interdisciplinary research on the carbon cycle has produced a set of analyses using long-term observations of several young and mature forests. Results from this work show that forest carbon storage has been increasing in these ecosystems and is not in balance with the carbon lost by respiration and decay. This result is contrary to the contemporary concept of near balance of carbon sources and sinks in mature forests.[15] The gain in forest carbon is typical of findings from U.S.-based large-scale networks, as well as observations made in mature forests in China. Evidence is therefore mounting that these sinks for atmospheric CO_2 offer significant potential for modulating the rate of atmospheric CO_2 increase.[16]

In western states, large changes in land cover and land use have occurred over the past century, with rapidly expanding urbanization along the Pacific coast and extensive agricultural development inland. Researchers exploring the effects of urbanization and agriculture on regional climate have found that irrigated agriculture in California tended to lower average and maximum near-surface air temperatures, while conversion of natural vegetation to urban areas tended to increase near-surface air temperatures. The surface temperature changes and their associated effects on the atmosphere also caused changes in the regional airflow. Overall, it was found that conversion of natural vegetation to irrigated agriculture has likely had a larger effect on the climate

of California than urban growth, but increased conversion of irrigated land to urban/suburban development could alter this conclusion.[17]

Scientists are concerned that increased permafrost thawing due to warming in Arctic regions could cause the release of substantial amounts of carbon long held in the frozen tundra. There appear to be two potential mechanisms for the carbon to reach the atmosphere: drainage of the carbon-rich river flow into the Arctic Ocean with subsequent emission, and direct respiration or recycling of the newly thawed carbon. Measurements made in the Yukon River basin in northern Canada have shown that the latter process predominates.[18]

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

The accuracy of estimates of future Earth system conditions at time scales ranging from months to centuries and at spatial scales ranging from regional to global has been significantly improved by CCSP research. The primary tools for Earth system prediction and projection are computer models that reflect the best available knowledge of Earth system processes. The following examples demonstrate the integration of observations and modeling necessary to contribute to the progress being made in CCSP Goal 3.

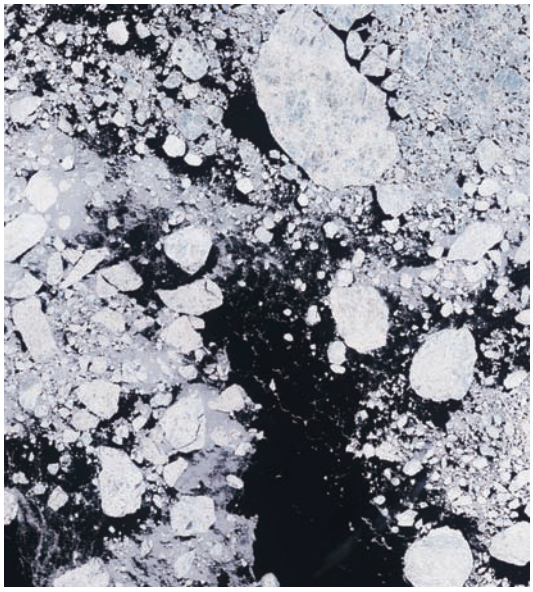
For a model to produce a realistic climate projection, it must include realistic representations of physical processes such as cloudiness, precipitation, and solar energy. Recent innovative studies using newly developed, detailed models of cloud processes that are coupled with a global climate model provide results that are significantly more consistent with observations than traditional cloud modeling techniques.[19] The incorporation of improved cloud representation in climate models is expected to reduce the uncertainty in predictions of the global and regional water cycle and surface climate.

Energy from the sun not reflected back to space provides the driving energy to Earth's weather and climate systems. Clouds are a major component in the global reflectance of sunlight. Year-to-year variability in the global reflectance is dominated by the variability of cloudiness in the tropics.[20] On the other hand, scientists have recently found little change in the year-to-year variability of reflectance at middle and high latitudes despite decreases in the highly reflective snow and sea ice cover. This result appears to be due to the compensating increase in cloud cover balancing the decreasing surface-level reflectance. Clouds continue to provide the largest source of uncertainty in model estimates of climate sensitivity, although a recent study finds evidence that, in

most climate models used in the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), clouds provide a positive feedback.[21]

Analyses of climate model simulations generated for the IPCC Fourth Assessment have identified several additional characteristics of climate change projections common to all of the models.[22] Examples of these robust model projections include strong sub-tropical drying, weakening of large-scale tropical atmospheric motions, and expansion of the poleward upper atmospheric wind pattern known as the Hadley circulation.

In another study, several models were used to investigate the effects of the freshwater input from melting ice and glaciers on the currents in the North Atlantic.[23] These currents are important due to their large-scale transport of heat. The study concluded that, in response to expected levels of freshwater input in the northern North Atlantic, the average modeled large-scale deep ocean current weakens by about 30% by the end of the century. All models simulate some weakening of this deep circulation, but no model simulates a complete shutdown of it.



CCSP researchers also use the geological record to test and apply climate models, particularly in cases where that knowledge has a bearing on climate change processes relevant to current society. One such analysis involves the largest known extinction in Earth's history, which took place approximately 250 million years ago at the Permian-Triassic boundary when approximately 95% of marine and 75% of terrestrial species were lost. In this study, a climate model simulation indicated that the elevated levels of CO_2 during this period led to climatic conditions inhospitable to both marine and terrestrial life.[24] It is hypothesized that a critical level of high-latitude warming was reached where the connection of oxygen-rich surface waters to the deep ocean was dramatically reduced—thus leading to a shutdown of marine biologic activity, which in turn led to increased atmospheric CO_2 and accelerated warming.

The historical record provides a broader set of observations to test and apply climate models to help reduce uncertainty in their future projections. A recent study used a simple model to attempt to reproduce paleoclimate reconstructions of Northern

Hemisphere temperature over the past seven centuries in response to estimated solar, volcanic, and greenhouse gas forcing during this period.[25] This study suggests that, for the current century, very high climate sensitivities predicted by some models for a doubling of atmospheric greenhouse gas concentrations are less likely than previously thought.

The projections made by CCSP research pertain not just to physical climate, but also to other components of the Earth system, including atmospheric chemistry. Continuing research has provided an estimate that the recovery of the Antarctic ozone hole will occur approximately 10 to 20 years later than the previous estimate of 2050.[26] As a result of the Montreal Protocol and its amendments, the use of ozone-depleting substances (ODS) has been greatly reduced. Improved understanding of atmospheric dynamics now gives 2001 as a better estimate of when the ODS peak occurred in the Antarctic stratosphere. This date is later than had been estimated previously and results in a longer projected time scale for recovery back to pre-1980 (unperturbed) levels of ODS.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Significant advances have been made in understanding the potential impacts of climate change. One of the characteristics of CCSP research is the use of many different sources of information, including analyses utilizing prehistoric information, direct observations, and model-based projections. Recent research also accounts for the dynamic nature of the response of human and natural systems to climate change. This research encompasses a wide range of potential impacts on societal needs such as water, health, and agriculture, as well as potential impacts on natural terrestrial and marine ecosystems. The integrated approach to developing the understanding sought in CCSP Goal 4 is illustrated in the following examples. This integration is occurring under several synthesis and assessment products (SAPs), particularly the seven products

under Goal 4. One example is the integration within SAP 4.1 that combines census population data, topographic elevation, shore protection, and land-use information to study the potential socioeconomic impact of various rates of sea-level rise.

Tools and research resulting from carbon cycle science are highly relevant to carbon management as demonstrated by a recent study that estimated the spatial variability of net primary production and potential biomass accumulation over the conterminous United States.[27] This study's model-based predictions indicate a potential to remove carbon from the atmosphere at a rate of 0.3 GtC per year through afforestation[c] of low-production crop and rangeland areas. This rate of carbon sequestration[d] would offset about one-fifth of the annual fossil fuel emissions of carbon in the United States.

The changing adaptability of coastal marshes is illustrated by the study of a coastal ecosystem. In a Chesapeake Bay marsh ecosystem, rising sea level, increasing CO_2, and high rainfall were shown to interact and improve the growth of a relatively tall bulrush at the expense of a hay-like cordgrass that grows in thick mats.[28] Such changes in species composition, caused by interacting global change factors, may influence the capacity of coastal marshes to rise in elevation at the pace required to keep abreast of sea-level rise because of species-specific differences in their ability to trap sediment and organic material.

Another example of the ecological consequences of climate change affecting adaptability involves the devastation of millions of acres of western U.S. and Canadian pines by bark beetles during the warmth and drought of 2000 to 2004. Recent modeling and observations revealed that beetles invading northernmost lodgepole pine trees are now only a few miles from previously pristine jack pine populations.[29] This may create a direct pathway of invasion to valued pine forests in the eastern United States and Canada.

CCSP's integrated approach to understanding the sensitivity and adaptability of natural ecosystems to climate change has also been applied in remote regions. The West Antarctic Peninsula is experiencing some of the largest, most rapid warming on Earth, which is causing loss of sea ice and increased snow precipitation. In turn, these changes are having major contrasting impacts on the adaptability of different penguin species. For example, in the vicinity of Anvers Island near the West Antarctic Peninsula during the last 3 decades, populations shifted south, so that local abundance of the ice-dependent and snow-intolerant Adelie penguins decreased by 65% (currently about

[c] Afforestation is the process of converting open land into forest by planting trees.
[d] Carbon sequestration is the process that removes carbon from the atmosphere, capturing and storing it by natural or artificial means.

5000), while the abundance of Chinstraps and Gentoos increased by 2,730% and 4,600% (currently about 300 and 650), respectively.[30] Climate warming in the Canadian Arctic has caused significant declines in total cover and thickness of sea ice and progressively earlier ice breakup in some areas. These changes affect the polar bear populations, causing them to extend their normal fast for longer periods during the open-water season.[31]

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

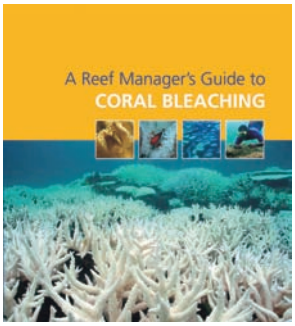
A substantial investment in basic research focused on global environmental variability and change has provided a significant set of opportunities for applying this knowledge in local, regional, and national planning. To explore and communicate the potential uses and limits of this knowledge, CCSP is using three approaches: developing scientific syntheses and assessments; exploring adaptive management and planning capabilities; and developing methods to support climate change policy inquiries. A few noteworthy examples of the progress made by CCSP in pursuing these approaches and actively working with the user community to apply this knowledge to manage risks and opportunities are described below.

CCSP scientists developed and documented a "water supply stress index" that calculates water shortage risks across the conterminous United States. The index is based on models and observations that integrate the effects of climate, land cover, and current water uses by municipalities and industries on water supply.[32] The water supply stress index and the methods associated with it will be used by local and regional decisionmakers to quantify the likelihood of future water shortages under changing climate, water, and land uses, for determining adaptation practices.

Incorporation of the subsurface water table into regional climate models is important, since land-cover changes produce significant effects on the water table and the hydrologic cycle. Shallow water tables can be either a sink or source of water to the surface soil depending on the relative balance of infiltration versus evaporation.[33] Recent studies using detailed observations and regional climate models have found that the fraction of rainfall that either recharges groundwater or ends up as streamflow tends to decrease when the fraction of land devoted to agriculture increases. This result suggests that intensive

agriculture can amplify surface water stresses, particularly during drought conditions.[34]

An example of regional decision support is the work carried out by the Consortium for Atlantic Regional Assessment (CARA), which is providing data and tools to help decisionmakers understand how outcomes of their decisions could be affected by potential changes in both climate and land use. On an interactive, user-friendly web site, CARA has organized data on climate (historical records and future projections from seven global climate models), land cover, and socioeconomic and environmental variables to help inform local and regional decisionmakers (see <www.cara.psu.edu>). The CARA tools and tutorials are designed to help decisionmakers understand the issues related to land-use and climate change by gathering, organizing, and presenting information for evaluating alternative mitigation strategies.



A workshop involving scientists and managers, co-led by several CCSP agencies under the auspices of the U.S. Coral Reef Task Force, resulted in the publication of *A Reef Manager's Guide to Coral Bleaching*.[35] The combined research results among state/territorial, Federal, academic, nongovernmental, and international scientists concluded that warming sea surface temperatures are a key factor in mass coral bleaching events. The *Guide* provides managers with strategies to support the natural resilience of coral reefs in the face of climatic change.

CCSP researchers have developed new metrics for estimating greenhouse gas emissions and carbon sequestration in the agricultural and forestry sectors.[36] These sectors can reduce atmospheric greenhouse gas concentrations by increasing carbon sequestration in biomass and soils, by reducing fossil fuel emissions through use of biomass fuels, and by substituting agricultural and forestry products that require less energy than other materials to produce. The DOE's National Greenhouse Gas Registry is using the new metrics as the basis for reporting greenhouse gas information from the agricultural and forestry sectors (see <www.eia.doe.gov/oiaf/1605/frntvrgg.html>).

CCSP FY 2008 Key Interagency Implementation Activities

The program's long-term vision, mission, goals, and objectives are described in the *CCSP Strategic Plan*. Implementation of this long-term plan occurs through agency activities that often benefit significantly from ongoing CCSP-facilitated coordination. CCSP has identified several key areas for FY 2008 that require particularly strong interagency coordination to achieve success; they cannot be adequately addressed by one agency alone. Although these priorities are only a small part of the overall program,

they are vital mechanisms through which CCSP will continue to integrate agency activities to create knowledge and products that are greater than the sum of the individual agency inputs. The development of CCSP interagency priorities is the result of a variety of planning processes, including planning processes within the 13 CCSP agencies (see Appendix A) and interagency planning conducted by the CCSP Interagency Committee (i.e., the Subcommittee on Global Change Research) and its subsidiary Interagency Working Groups. CCSP's interagency planning is informed by external advice from several NRC committees. CCSP's annual implementation priorities are logical evolutions of the program's interagency approaches to the priorities established in the *CCSP Strategic Plan*. The selection criteria for these activities require that they are founded upon a solid intellectual basis and are of high scientific quality; require coordination and/or integration across multiple CCSP agencies to create value-added products and services that cannot be created by any one agency alone; improve the characterization of key areas of scientific uncertainty and/or improve decision-support tools; provide a timely response to a particular need or leveraging opportunity; and are cost-effective.

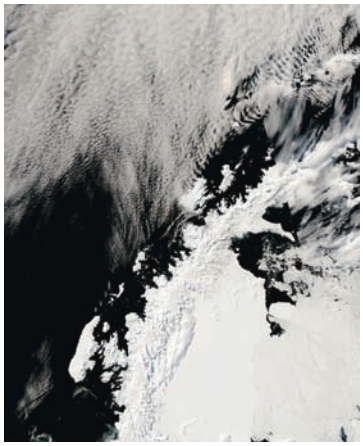
The interagency implementation priorities generally represent only a fraction of CCSP's portfolio. The focus areas are listed here in an order similar to the research elements described in the *CCSP Strategic Plan*. However, due to their integrative nature they do not follow a one-to-one mapping to the research elements.

Understanding Aerosol Forcing and Interactions with Clouds and Non-CO_2 Trace Gases. The key objectives of this set of activities are to quantify the effects of atmospheric aerosols (tiny airborne particles) on radiation and on clouds, to quantify the modification of the radiation balance by non-CO_2 greenhouse gases, and to quantify the influence of the chemistry of the lower atmosphere on both aerosols and non-CO_2 greenhouse gases. Research will include use of newly initiated and enhanced measurements of water vapor in the upper troposphere and the lower stratosphere and water vapor's role in altering climate directly and via its influence on aerosols, cirrus clouds, and chemical composition. Studies on the potential contributions of air pollution and aviation to global climate forcing will be extended. In addition, field missions are planned to understand the properties of absorbing aerosols and their precursors and their transport to the Arctic polar region as a part of the International Polar Year, in an effort to quantify the contribution of absorbing aerosols to the melting of the Arctic ice.

Development of an Integrated Earth System Analysis Capability. By combining global observations of the atmosphere, ocean, land, biosphere, and ice-covered areas with models that dynamically couple these components of the Earth system, it will be possible to produce internally consistent maps (i.e., "analyses") of the state of the planet. Time series of such analyses will allow researchers to better explain observed changes in the climate system and will allow decisionmakers to develop more informed options to address future changes. Additional reanalysis activities in FY 2008 will include an improved treatment of the hydrological cycle and efforts to extend atmospheric reanalyses to span the entire 20th century. Further advances in producing integrated Earth system analyses will require progress in ongoing efforts to construct models that properly simulate the interactions among the physical and biogeochemical processes in the climate system.

Carbon Cycle Research Integration. CCSP's carbon cycle research element will integrate the research efforts of the North American Carbon Program and relevant aspects of the Ocean Carbon and Climate Change Program to better quantify and understand the carbon budget of North America and adjacent ocean basins, including terrestrial, freshwater, oceanic, and atmospheric sources and sinks, the underlying processes, and the dynamics that determine influences on atmospheric CO_2 and methane (CH_4). This integration will clarify and reduce uncertainties about the North American carbon budget and provide better information for decisions about carbon management. Improved observations, methods, and understanding of carbon cycling will be integrated into global models and analysis systems to provide more reliable capabilities for studying and predicting future changes in atmospheric CO_2 and CH_4 and carbon storage by terrestrial and oceanic ecosystems.

Abrupt Changes in a Warming Climate. Paleoclimate research indicates that major shifts in regional and global climate have occurred on time scales as short as decades, severely affecting rainfall patterns, droughts, ecosystems, and human civilizations.[1] Assessing the potential for future abrupt changes and implementing the capability to diagnose and predict their occurrence will require concerted efforts to improve Earth system analysis, decadal forecasting capabilities, reconstructions of past abrupt climate change, and understanding of societal impacts. Activities in FY 2008 will emphasize model experiments designed to test potential mechanisms for abrupt change, and paleoclimate research on patterns, causes, and impacts of past abrupt climate events. Both activities will help set



priorities for enhanced monitoring with the goal of developing an abrupt change early warning system. These efforts are integrated with the *Ocean Research Priorities Plan* near-term priority on the meridional overturning circulation of the Atlantic Ocean.[2]

Potential Effects of Climate Change on the Biodiversity and Productivity of Ecosystems. Research will include new activities on two topics of urgency: (1) vulnerability of coastal ecosystems, both terrestrial and aquatic, to climate-related changes, including sea-level rise, increased sedimentation and runoff, increased storm frequency or intensity, saltwater intrusion, and oceanic warming; and (2) warming-induced changes in high-latitude and high-elevation ecosystems, including changes in species composition, alterations in the timing of water availability, migration of the tree line, retreat of glaciers, and loss of permafrost and sea ice. Both these topics require additional research on underlying ecological processes and development of models linking geophysical and ecological phenomena.

Integration of Water Cycle Observations, Research, and Modeling. The FY 2008 interagency priority for the global water cycle is the initiation of a multi-year activity that is planned to include a series of integrated projects, each building upon the experience gained from previous years. FY 2008 activities will focus on a few regional case studies in which both models and measurements will be used to develop closure in the terrestrial water cycle budget for those regions. This multi-agency CCSP project will utilize existing regional sites to improve observational capabilities (surface, subsurface, and remote sensing). A range of climate zones will be considered to provide a suitable research framework that concurrently addresses climate/water cycle science and water resource management issues. Enabling links with other projects will be explored through the Hydrological Information System portal, including data/product delivery to the National Integrated Drought Information System (NIDIS). In future years, an expansion in scope is envisaged to encompass time scales from seasonal to interannual and spatial scales from local to regional to global. This activity is designed to benefit both the broader research community as well as the operational applications community through a more accurate quantification of the water cycle and improved mathematical formulations of physical processes. Results will be incorporated into climate and hydrologic prediction models.

Land-Use and Land-Cover Change and Climate: Interactions and Critical Observations. Land-use and land-cover priorities include understanding historic, current, and potential future land-use and land-cover change patterns, dynamics, and drivers; understanding the mutual effects and feedbacks between climate variability and land use/land cover; and forecasting environmental, social, economic, and human health consequences. All of these land-use and land-cover change priority issues directly

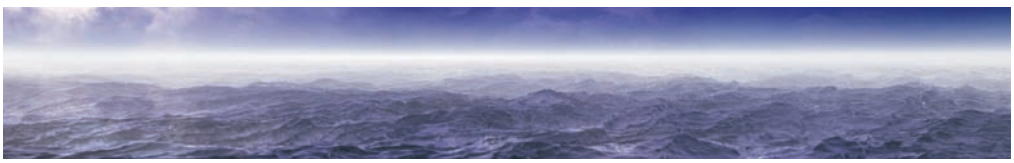
influence climate by affecting atmospheric trace gas composition and surface reflectance, and are thus critical to a broad spectrum of CCSP interests. The collection, archiving, and subsequent scientific use of global Landsat data from 2005 to 2006 is a priority for FY 2008, through the "mid-decadal Landsat data collection effort." The FY 2008 priority also includes support for the Landsat Data Continuity Mission that is under development to continue the collection of global Landsat data. Without these satellite observations, the current pace of discovery and innovation in global land-use and land-cover change climate research would not be possible.

Coping with Drought through Research and Regional Partnerships. Building trust and collaborative efforts with stakeholders to help them take advantage of climate information, especially in the area of drought planning, is a long-term effort that requires consistent and continual interactions. Research in this area will focus on the development of methods, models, and mechanisms for integrating climate information into analyses of the social and economic ramifications of drought as well as the policy and decisionmaking processes in the face of drought. Scientific data products will include paleoclimatic and historical information about drought and its impacts, seasonal-to-interannual scale observations and predictions of drought, and longer term projections of decadal-to-centennial scale variability and change. Social and economic impact analyses including historical perspectives and near-term trends such as projections of water conflicts, water demand, population changes, and land-use changes will be used to augment the physical science analyses. This effort is linked to NIDIS.

Decision Support: Information to Support Policy Development and Adaptive Management

CCSP sponsors and conducts research that is ultimately related to policy and adaptive management decisionmaking. CCSP's decision-support approach is guided by several general principles, including:

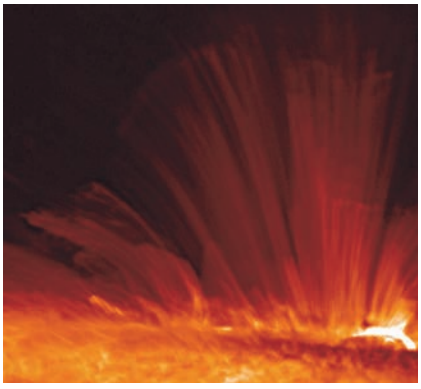
- Early and continuing involvement of stakeholders
- Explicit treatment of uncertainties
- Transparent public review of analysis questions, methods, and draft results
- Evaluation of lessons learned from ongoing and prior decision-support and assessment activities.



Synthesis and Assessment Products

CCSP is generating synthesis and assessment products that integrate research results focused on key issues and related questions frequently raised by decisionmakers. Current evaluations of the science can be used for informing public debate, policy development, and adaptive management decisions and for defining and setting the future direction and priorities of the program. The synthesis and assessment products constitute an important new form of topic-driven integration of U.S. global change assessment efforts. These CCSP products will be U.S. Government reports, subject to the provisions of the Information Quality Act (Section 515 of the Treasury and General Government Appropriations Act of 2001) and the Federal Advisory Committee Act Amendments of 1997 [P.L. 105-153, Sec. 2(A), (B), Dec. 17, 1997, 111 Stat. 2689].

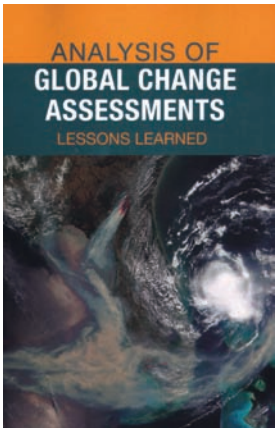
The synthesis and assessment products are generated by researchers in a process that involves review by experts, public comment from stakeholders and the general public, and final approval by the departments/agencies involved in CCSP. Formal endorsement of the products by the Federal Government enhances their value for decisionmakers and the public at large. The program has prepared guidelines that describe steps to be followed in each of three phases of the preparation process: developing the prospectus, drafting and revising, and final approval and publication. This methodology for product development facilitates involvement of the research community and user groups in ensuring that the products are focused in a useful fashion and meet the highest standards of scientific excellence. The guidelines also encourage transparency by ensuring that public information about the status of the products will be provided through the *Federal Register*, on the CCSP web site, and other means throughout the review and clearance process. If further clarification of specific issues is required, the NRC will provide advice on an as-needed basis to the lead agency responsible for the preparation of each product.



The first two products generated through this process have been completed and several others are nearing completion. Up-to-date information on the status of all SAPs can be obtained from <www.climatescience.gov/Library/sap>, including information on opportunities for public comment on draft products. A listing of each of the 21 synthesis and assessment products by CCSP goal is provided in Chapter 7 of this report.

"Lessons Learned" in Decision Support and Assessment

To build on the experiences of earlier assessment activities, CCSP requested that the NRC carry out an analysis of global change assessments that have addressed topics broadly similar to those encompassed by CCSP. The study, which was released in early 2007, included a comparative analysis of past assessments that address issues directly related to the science and technical issues of CCSP. The committee concluded that global change assessments are critical for informing decisionmakers. In identifying essential properties of a successful assessment it stressed that future assessment processes must communicate relevant information to the user, address the technical quality of the information, and demonstrate fairness and impartiality in the assessment process. The report identifies a number of essential elements that increase the probability that an assessment will effectively inform decisionmakers and other target audiences. CCSP will take into account the findings of the NRC in its future assessment activities.



Outline of Research Element Activities

The CCSP-participating agencies coordinate scientific research through a set of linked interdisciplinary research elements and cross-cutting activities that encompass a wide range of interconnected issues of climate and global change. Chapters 3 to15 of the *CCSP Strategic Plan* contain more detailed discussions of the research elements as well as activities that cut across all areas of the program. This report focuses on highlights of recent research and program plans for FY 2008.

Atmospheric Composition. The composition of the atmosphere at global and regional scales influences climate, air quality, stratospheric ozone, and precipitation, which in turn affect human health and the vitality of ecosystems. Research and observational activities coordinated and supported by CCSP are being used to assess how human activities and natural processes affect atmospheric composition, and how that understanding may be used to inform decisionmaking in the United States and abroad. In FY 2008, emphasis will be given to studies of interactions between aerosols and non-CO_2 gases, enhanced measurements of atmospheric water vapor, and interactions of pollutants with climate change. Special emphasis will be given to the climate impacts of pollutants associated with aviation.

See CCSP Strategic Plan Chapter 3.

Climate Variability and Change (including Climate Modeling). Recognizing that the climate system operates seamlessly across a wide spectrum of time scales, CCSP-supported research encompasses both short-term climate variability and longer term climate change. Addressing the interaction of climate processes across time scales poses challenges not only in designing observation systems to monitor the climate system adequately, but also in constructing models that can properly reproduce its past and confidently project its future behavior. Earth system models, in combination with global Earth observations, must produce internally consistent maps of atmospheric, oceanic, land surface, and ice conditions both in near real-time and retrospectively. These maps, or "analyses," will provide decisionmakers with tools to visualize the evolving state of the full climate system over the entire planet, and researchers with the ability to better explain observed changes in the climate system.

See CCSP Strategic Plan Chapters 4 and 10.

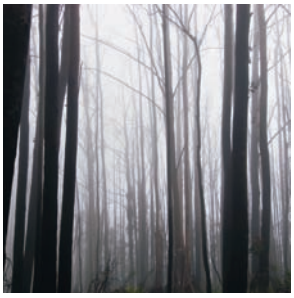
Global Water Cycle. Research associated with this element involves studies of the crucial role the water cycle plays both in climate variability, climate change, and the influence climate has on aspects of the global water cycle for which society and nature critically depend. Through countless interactions in the Earth system, the global water cycle integrates physical, chemical, and biological processes that sustain ecosystems and influence climate and related global change. The ultimate goal of the CCSP water cycle research is to provide a better foundation for decisions and investments by policymakers, managers, and individuals. Achieving this goal requires a program of activities that test predictions and data products in real decision contexts, demonstrate techniques and their effectiveness to potential users, and provide tools and strategies to transfer the science from the experimental realm to operations. In FY 2008, emphasis will be given to coordinated observations and modeling of selected sites, at the river basin or catchment scale, to improve understanding of terrestrial water cycle processes leading to better closure constraints on water budgets at this scale. The improvements to land surface and hydrological models resulting from this research will lead to an enhanced ability to more accurately represent global change projections at the regional scales that affect water resources and other water cycle-dependent applications sectors.

See CCSP Strategic Plan Chapter 5.

Land-Use and Land-Cover Change. Land use and land cover are linked to climate and weather in complex ways and are critical inputs for modeling greenhouse gas emissions, carbon balance, and ecosystems. Land-use and land-cover change (LULCC) studies have provided critical inputs to large-scale biomass and forest cover assessments; future LULCC goals include reducing uncertainties in biomass estimates, understanding regional heterogeneities in changes, and quantifying linkages and feedbacks between LULCC, climate change, and other human and environmental components. Research

that examines historic, current, and future LULCC, its drivers, feedbacks to climate, and its environmental, social, economic, and human health consequences is therefore of utmost importance and often requires interagency and intergovernmental cooperation. Research plans focus on how management practices may change as climate and conservation policies change, and feedbacks related to environmental, social, economic, and human health.

See CCSP Strategic Plan Chapter 6.



Global Carbon Cycle. Increasing levels of atmospheric CO_2 and CH_4 are major drivers of climate change. The global carbon cycle element of the CCSP seeks to better quantify and understand the dynamics of the global carbon cycle that determine CO_2 and CH_4 fluxes and carbon storage in terrestrial and oceanic ecosystems. Carbon cycle processes depend on climate, thus linking carbon cycle and climate change analyses is critical. Carbon cycle research involves multiple disciplines and extends over a broad range of spatial and temporal scales. Major multi-agency activities include the North American Carbon Program (NACP), an effort to describe and reduce uncertainties about the North American carbon budget and underlying processes, and the Ocean Carbon and Climate Change (OCCC) Program, a research effort aimed at determining how climate change will affect the future behavior of the oceanic carbon sink. In FY 2008, the NACP will address key gaps and uncertainties in the carbon syntheses developed previously, and aspects of the OCCC and NACP will be coordinated to better quantify and understand the roles of adjacent ocean basins in the North American carbon budget. NASA will launch the Orbiting Carbon Observatory (OCO) to provide, for the first time, consistent atmospheric carbon observations globally from space, and carbon data assimilation systems will begin to derive estimates of carbon sources and sinks from these measurements.

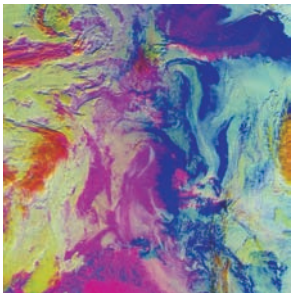
See CCSP Strategic Plan Chapter 7.

Ecosystems. This research element studies the potential effects of global change on goods and services provided by aquatic and terrestrial ecosystems, using observations, experiments, modeling, and syntheses to focus on critical emerging questions. Newly initiated projects in terrestrial ecosystems are addressing cause-and-effect relationships between climatic variability and change and the distribution, abundance, and productivity of native and invasive organisms. Further, research is continuing into understanding how increasing CO_2 levels affect plants and microorganisms. Research in a Chesapeake Bay ecosystem is generating data to evaluate and forecast effects of warming, changes in fishing pressure, and eutrophication on economically important estuarine ecosystems. In the ocean, coral reef research is helping scientists and managers identify climatic and non-climatic stressors and thereby better manage these important ecosystems.

See CCSP Strategic Plan Chapter 8.

Decision-Support Resources Development and Related Research on Human Contributions and Responses. Decisionmakers and other interested citizens need reliable science-based information to make informed judgments regarding policy and actions to address the risks and opportunities of variability and change in climate and related systems. A wide variety of CCSP decision-support resources and related research on human contributions and responses is targeted at that objective. The outcomes of these activities are intended to inform public discussion of climate-related issues and to scientifically assess and expand options for mitigation of and adaptation to climate variability and change. The most prominent of CCSP's ongoing decision-support activities is its synthesis and assessment process that involves the generation of 21 different products intended to support public discussion of climate science issues of particular importance to U.S. decisions. CCSP's research on human contributions and responses to global environmental variability and change includes analyses of human drivers of change and their potential impact, societal resilience and ways of reducing vulnerability, approaches for improving the ability of decisionmakers to utilize scientific information, and the effects of global environmental change on human health. CCSP's research is paying particular attention to aspects of global change that have greatest relevance to society, including drought and extreme or abrupt climate events.

See CCSP Strategic Plan Chapters 9 and 11.



Observing and Monitoring the Climate System. CCSP provides active stewardship for observations that document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society. Some of these observations are not part of the CCSP budget (e.g., operational satellites) but are crucial to its success. A core CCSP activity is U.S. participation in the broad-based strategy of the international Global Climate Observing System (GCOS) in monitoring atmospheric, oceanic, and terrestrial domains with an appropriate balance of *in situ* and remotely sensed observations. In FY 2008, observing activities by CCSP agencies will focus on observing the polar climate as part of the International Polar Year (IPY) series of international cooperative studies. The IPY plans to advance polar observations by establishing a variety of new multidisciplinary observatories using the latest technologies in sensor web (network of spatially distributed sensor platforms that wirelessly communicate with each other) and power-efficient designs. Data from these, as well as more traditional surface- and space-based observatories, will initiate long-term, high-quality sustained measurements needed to detect future climate change. The United States plans to increase its efforts on observations of the polar atmosphere, ice, and ocean, as well as leverage its investments in polar research with international partners. A continuing challenge to CCSP agencies is ensuring the long-term integrity and understandability of data products provided by remote sensing and *in situ* observing systems.

See CCSP Strategic Plan Chapters 12 and 13.

Communication. CCSP's member agencies support a broad array of communication initiatives. CCSP has developed a strategy and implementation plan for helping to coordinate and facilitate these activities. These efforts are intended to improve public understanding of climate change research by disseminating the results of CCSP activities credibly and effectively, and by making CCSP science findings and products easily available to a diverse set of audiences. CCSP facilitates communication of the results of individual agencies, as well as providing coordination in communicating the results of climate activities of the Federal Government.

See CCSP Strategic Plan Chapter 14.

International Research and Cooperation. CCSP, through its working groups including the Interagency Working Group on International Research and Cooperation, participates in and provides input to major international scientific and related organizations on behalf of the U.S. Government and scientific community. CCSP also provides support to maintain the central infrastructure of several international research programs and international activities that complement CCSP and U.S. Government goals in climate science.

See CCSP Strategic Plan Chapter 15.

THE U.S. CLIMATE CHANGE SCIENCE PROGRAM FOR FY 2008 CHAPTER REFERENCES

1) **IPCC**, 2007: Climate Change 2007: *The Physical Science Basis – Summary for Policymakers, Technical Summary, and Frequently Asked Questions* [Solomon, S., D. Qin, M. Manning, Z. Chen, M.C. Marquis, K. Averyt, M. Tignor, and H.L. Miller (eds.)]. World Meteorological Organization, Geneva, Switzerland, 142 pp.
2) **NSTC** Joint Subcommittee on Ocean Science and Technology, 2007: *Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy*. Washington, DC., 84 pp. Available at <ocean.ceq.gov/about/docs/orppfinal.pdf>.
3) **Dirmeyer**, P.A. and K.L. Brubaker, 2006: Trends in the Northern Hemisphere water cycle. *Geophysical Research Letters*, **33**, L14712, doi:10.1029/2006GL026359.
4) **Rignot**, E. and P. Kanagaratnam, 2006: Changes in the velocity structure of the Greenland Ice Sheet. *Science,* **311**, 986.
5) **Velicognia**, I. and J. Wahr, 2006: Measurements of time-variable gravity show mass loss in Antarctica. *Science,* **311**, 1754.
6) **Stolarski**, R.S., A.R. Douglass, M. Gupta, P.A. Newman, S. Pawson, M.R. Schoeberl, and J.E. Nielsen, 2006: An ozone increase in the Antarctic summer stratosphere: A dynamical response to the ozone hole. *Geophysical Research Letters*, **33**, L21805, doi:10.1029/2006GL026820.
7) **Jiang**, X., S.J. Eichelberger, D.L. Hartmann, and Y.L. Yung, 2007: Influence of doubled CO_2 on ozone via changes in the Brewer-Dobson Circulation. *Journal of the Atmospheric Sciences* (in press).
8) **Wong**, T., B.A. Wielicki, R.B. Lee, III, G.L. Smith, and K.A. Bush, 2006: Re-examination of the observed decadal variability of Earth radiation budget using altitude-corrected ERBE/ERBS non-scanner WFOV data. *Journal of Climate*, **19**, 4028-4040.
9) **Emanuel**, K., 2006: Climate and tropical cyclone activity: a new model downscaling approach. *Journal of Climate*, **19**, 4797-4802.
10) **Hoyos**, C.D., P. Agudelo, P. Webster, and J. Curry, 2006: Deconvolution of the factors leading to the increase in global hurricane intensity. *Science*, **312**, 94-97.
11) **Kossin,** J.P., K.R. Knapp, D.J. Vimont, R.J. Murnane, and B.A. Harper, 2007: A globally consistent reanalysis of hurricane variability and trends. *Geophysical Research Letters*, **34(4)**, L04815, doi:10.1029/2006GL028836.
12) **Santer**, B.D., T.M.L. Wigley, P.J. Gleckler, C. Bonfils, M.F. Wehner, K. AchutaRao, T.P. Barnett, J.S. Boyle, W. Brüggemann, M. Fiorino, N. Gillett, J.E. Hansen, P.D. Jones, S.A. Klein, G.A. Meehl, S.C.B. Raper, R.W. Reynolds, K.E. Taylor, and W.M. Washington, 2006: Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academy of Sciences*, **103**, 13905-13910, doi:10.1073/pnas.0602861103.
13) **Landsea**, C.W., B.A. Harper, K. Hoarau, and J.A. Knaff, 2006: Can we detect trends in extreme tropical cyclones? *Science*, **313**, 452-454.
14) **Randerson**, J.T., H. Liu, M.G. Flanner, S.D. Chambers, Y. Jin, P.G. Hess, G. Pfister, M.C. Mack, K.K. Treseder, L.R. Welp, F.S. Chapin, J.W. Harden, M.L. Goulden, E. Lyons, J.C. Neff, E.A.G. Schuur, C.S. Zender, 2006: The impact of boreal forest fire on climate warming. *Science*, **314**, 1130-1132, doi:10.1126/science.1132075.
15) **Zhou,** G., S. Liu, Z. Li, D. Zhang, X. Tang, C. Zhou, J. Yan, and J. Mo, 2006: Old-growth forests can accumulate carbon in soils. *Science*, **314**, 1417, doi:10.1126/science.1130168.
16) **Urbanski**, S., C. Barford, S. Wofsy, C. Kucharik, E. Pyle, J. Budney, K. McKain, D. Fitzjarrald, M. Czikowsky, and J.W. Munger, 2007: Factors controlling CO_2 exchange on time scales from hourly to decadal at Harvard Forest. *Journal of Geophysical Research*, **112**, G02020, doi:10.1029/2006JG000293.
17) **Kueppers**, L.M., M.A. Snyder, and L.C. Sloan, 2007: Irrigation cooling effect: Regional climate forcing by land-use change. *Geophysical Research Letters*, **34**, L03703, doi:10.1029/2006GL028679.
18) **Guo**, L., and R.W. Macdonald, 2006: Source and transport of terrigenous organic matter in the upper Yukon River: Evidence from isotope ($\delta^{13}C$, $\Delta^{14}C$, $\delta^{15}N$) composition of dissolved, colloidal, and particulate phases. *Global Biogeochemical Cycles*, **20**, GB2011, doi:10.1029/2005GB002593.

THE U.S. CLIMATE CHANGE SCIENCE PROGRAM FOR FY 2008 CHAPTER REFERENCES (CONTINUED)

19) **Ovtchinnikov**, M., T. Ackerman, R. Marchand, and M. Khairoutdinov, 2006: Evaluation of the multiscale modeling framework using data from the Atmospheric Radiation Measurement Program. *Journal of Climate*, **19**, 1716-1729, doi:10.1175/JCLI3699.1.

20) **Loeb**, N.G., B.A. Wielicki, F.G. Rose, and D.R. Doelling, 2006: Variability in global top-of-atmosphere shortwave radiation between 2000 and 2005. *Geophysical Research Letters*, **34**, L03704, doi:10.1029/2006GL028196.

21) **Soden**, B.J. and I.M. Held, 2006: An assessment of climate feedbacks in coupled ocean-atmosphere models. *Journal of Climate*, **19**, 3354-3360.

22) **Held**, I. and B. Soden, 2006: Robust responses of the hydrological cycle to global warming. *Journal of Climate*, **19**, 5686-5699.

23) **Stouffer**, R.J., J. Yin, J.M. Gregory, K.W. Dixon, M.J. Spelman, W. Hurlin, A.J. Weaver, M. Eby, G.M. Flato, H. Hasumi, A. Hu, J.H. Jungclaus, I.V. Kamenkovich, A. Levermann, M. Montoya, S. Murakami, S. Nawrath, A. Oka, W.R. Peltier, D.Y. Robitaille, A. Sokolov, G. Vettoretti, and S.L. Weber, 2006: Investigating the causes of the response of the thermohaline circulation to past and future climate changes. *Journal of Climate,* **19**, 1365-1387.

24) **Kiehl,** J.T. and C.A. Shields, 2005: Climate simulation of the latest Permian: Implications for mass extinction. *Geology*, **33**, 757-760.

25) **Hegerl**, G.C., T.J. Crowley, W.T. Hyde, and D.J. Frame, 2006: Climate sensitivity constrained by temperature reconstructions over the past seven centuries. *Nature*, **440(7087)**, 1029-1032, doi:10.1038/nature04679.

26) **Newman**, P.A., E.R. Nash, S.R. Kawa, S.A. Montzka, and S.M. Schauffler, 2006: When will the Antarctic ozone hole recover? *Geophysical Research Letters*, **33**, doi:10.1029/2005GL025232.

27) **Potter**, C., S. Klooster, S. Hiatt, M. Fladeland, V. Genovese, and P. Gross, 2007: Satellite-derived estimates of potential carbon sequestration through afforestation of agricultural lands in the United States. *Climatic Change,* **80**, 323-336, doi:10.1007/s10584-006-9109-3.

28) **Erickson**, J.E., J.P. Megonigal, G. Peresta, and B.G. Drake, 2007: Salinity and sea level mediate elevated CO_2 effects on C_3 and C_4 plant interactions and tissue nitrogen in a Chesapeake Bay tidal wetland. *Global Change Biology,* **13**, 202-215, doi:10.1111/j.1365-2486.2006.01285.x.

29) **Logan**, J.A. and J.A. Powell, 2007: Ecological consequences of forest-insect disturbance altered by climate change. In *Climate Change in Western North America: Evidence and Environmental Effects* [Wagner, F.H. (ed.)]. University of Utah Press, Salt Lake City, Utah (in press).

30) **Ducklow**, H.W., K. Baker, D.G. Martinson, L.B. Quetin, R.M. Ross, R.C. Smith, S.E. Stammerjohn, M. Vernet, and W. Fraser, 2007: Marine pelagic ecosystems: The West Antarctic Peninsula. *Philosophical Transactions of the Royal Society B: Biological Sciences,* **362(1477)**, 67-94, doi:10.1098/rstb.2006.1955.

31) **Stirling**, I. and C.L. Parkinson, 2006: Possible effects of climate warming on selected populations of polar bears in the Canadian Arctic. *Arctic*, **59(3)**, 261-275.

32) **Sun**, G., C. Li, C.C. Trettin, J. Lu, and S.G. McNulty, 2006: Simulating the biogeochemical cycles in cypress wetland-pine upland ecosystems at a landscape scale with the wetland-DNDC model. *Hydrology and Management of Forested Wetlands, Proceedings of the International Conference 8-12 April 2006*. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

33) **Fan**, Y., G. Miguez-Macho, C. Weaver, R. Walko, and A. Robock, 2007: Incorporating water table dynamics in climate modeling, part I: water table observations and the equilibrium water table. *Journal of Geophysical Research*, **112**, D10125, doi: 10.1029/2006JD008111.

34) **Jayawickreme**, D.H. and D.W. Hyndman, 2007: Evaluating the influence of land cover on seasonal water budgets using NEXRAD rainfall and streamflow data. *Water Resources Research*, **43**, W02408, doi:10.1029/2005WR004460.

35) **Marshall**, P.A. and H.Z. Schuttenberg, 2006: *A Reef Manager's Guide to Coral Bleaching*. Great Barrier Reef Marine Park Authority, Townsville, Australia, 163 pp.

36) **Birdsey**, R.A. 2006. Carbon accounting rules and guidelines for the United States forest sector. *Journal of Environmental Quality*, **35**, 1518-1524.

HIGHLIGHTS OF RECENT RESEARCH AND PLANS FOR FY 2008

1 Atmospheric Composition

Strategic Research Questions

3.1 What are the climate-relevant chemical, microphysical, and optical properties, and spatial and temporal distributions, of human-caused and naturally occurring aerosols?

3.2 What are the atmospheric sources and sinks of the greenhouse gases other than CO_2 and the implications for the Earth's energy balance?

3.3 What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?

3.4 What are the characteristics of the recovery of the stratospheric ozone layer in response to declining abundances of ozone-depleting gases and increasing abundances of greenhouse gases?

3.5 What are the couplings and feedback mechanisms among climate change, air pollution, and ozone layer depletion, and their relationship to the health of humans and ecosystems?

See Chapter 3 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The composition of the atmosphere on global and regional scales influences climate, air quality, the stratospheric ozone layer, and weather. The interactions have impacts on human health and the vitality of ecosystems and hence have high relevance to society. CCSP research on atmospheric composition focuses primarily on how human activities and natural processes affect atmospheric composition, and how these changes in turn relate to societal issues. The issues embrace multiple disciplines, cross many spatial scales, and are highly interrelated. As a consequence, the CCSP research is a highly coordinated endeavor that involves observational studies, laboratory investigations, and diagnostic and modeling analyses to provide the timely, accurate, and useful scientific information needed by decisionmakers in the United States and abroad.

Much progress has been made to date in understanding the role of atmospheric composition in Earth's climate. Efforts have focused on the areas of largest uncertainty in understanding how atmospheric constituents other than carbon dioxide affect the forcing of climate. Atmospheric fine particles ("aerosols") can have either warming or cooling effects, depending on many factors. CCSP research has made progress in defining those factors, and has recently taken steps to address the next levels of complexity in the issue by looking at the interactions of aerosols with clouds. For FY 2008, CCSP's Atmospheric Composition research will advance further to investigate how water vapor, an ever-present climate gas, affects climate. Because water vapor is linked to trace gases, aerosols, and clouds, CCSP research will be addressing some of the most highly interrelated, multidimensional aspects of climate forcing.

Highlights of Recent Research

The following paragraphs provide selected highlights of recent research supported by CCSP-participating agencies.

Protecting Earth's Ozone Layer Also Helped Slow Climate Change.[1] A 1987 international agreement to reduce ozone-depleting chemicals has also slowed global warming by years, according to a new study by CCSP scientists and their colleagues. The double effect occurred because compounds that destroy the atmosphere's ozone layer also act as greenhouse gases. The ozone layer shields the Earth from harmful ultraviolet radiation. To protect this layer, nations around the world signed the Montreal Protocol in 1987 to control the production and use of ozone-depleting substances. While protecting the ozone layer, the Montreal Protocol and its Amendments have also cut in half the amount of greenhouse warming caused by ozone-destroying chemicals that would have occurred by 2010 had these substances continued to build unabated in Earth's atmosphere. The amount of warming that was avoided is equivalent to 7 to 12 years of rise in carbon dioxide (CO_2) concentrations in the atmosphere during the 2000 to 2010 time frame. Earlier studies showed that continued growth in ozone-depleting substances would lead to significant warming of Earth's climate. The new analysis quantifies the near-term climate benefits of controlling these substances (see Figure 1).

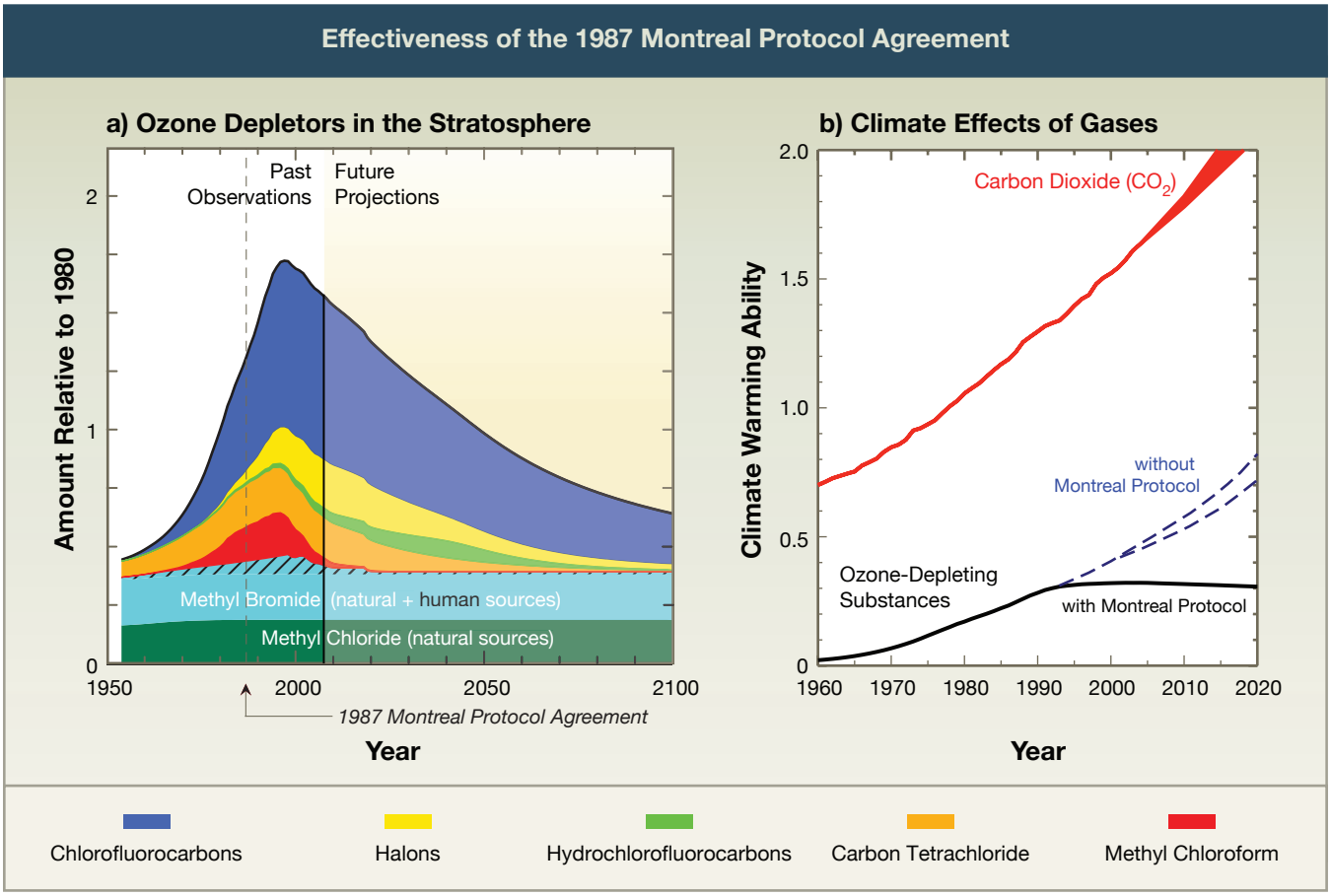
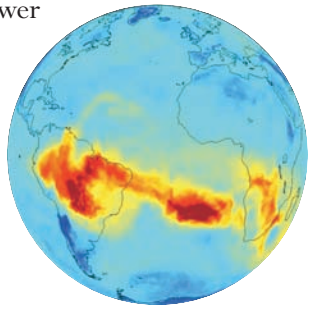


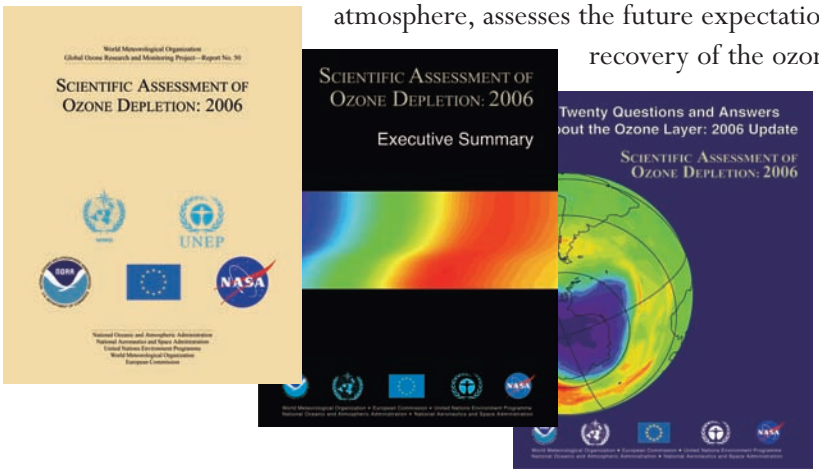
Figure 1: Effectiveness of the 1987 Montreal Protocol Agreement. Past, present, and projected future abundances of ozone-depleting substances in the stratosphere show the effectiveness of the 1987 Montreal Protocol agreement that reduced worldwide use of these substances (panel a). Because ozone-depleting substances are also greenhouse gases, the Montreal Protocol and its amendments gave an early start to slowing climate warming (panel b). The left axis (Climate Warming Ability) gives the climate forcing in units of watts per meter squared (Wm^{-2}). *Credit: G.J.M. Velders, Netherlands Environmental Assessment Agency; S.O. Andersen, USEPA; J.S. Daniel, NOAA; D.W. Fahey, NOAA; and M. McFarland, DuPont Fluoroproducts.*

Satellite Studies of Water Vapor and Ozone-Depleting Gas Transport.[2] Analyses of Aura satellite observations of water vapor and carbon monoxide at high altitudes, and their comparison with model calculations, show that thunderstorms over Tibet provide a pathway for water vapor and chemicals to travel from the lower atmosphere into the stratosphere. Since water vapor has a strong influence on climate, learning how it reaches the stratosphere can help improve climate prediction models. Similarly, understanding the pathways that ozone-depleting chemicals can take to reach the stratosphere is essential for understanding future threats to the ozone layer.



Improved Estimates of the Recovery of the Antarctic Ozone Hole.[3] CCSP research has improved our understanding of atmospheric motions that transport ozone-depleting substances from the lower atmosphere to the Antarctic stratosphere, showing that this transport is slower than previously estimated. As a result, the revised estimate for recovery of Antarctic ozone will occur about 15 years later than previously thought, in approximately 2065 instead of 2050. Such research during the ozone layer's recovery phase is crucial for policymakers.

Completion of International Assessment of the Ozone Layer.[4] CCSP researchers played key roles in the completion of the international state-of-understanding assessment of the ozone layer, which was provided in FY 2007 to the over 190 nations (including the United States) that are Parties to the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer. The *Scientific Assessment of Ozone Depletion: 2006* summarizes current understanding regarding the extent of ozone depletion globally and at the poles, describes the current abundances of ozone-depleting gases in the atmosphere, assesses the future expectations for the recovery of the ozone layer and its relation to possible future climate change, and updates the past, current, and expected future status of ultraviolet radiation at the Earth's surface. CCSP researchers were prominent in the leadership, preparation, and review of the assessment—a 2-year endeavor that involved over 300 scientists from 31 countries around the globe. Global decisionmakers will consider the information in the over 500 pages of the report as they discuss possible future actions to protect the stratospheric ozone layer.



Field and Laboratory Investigations on Atmospheric Composition and Climate.[5,6,7] A combination of field experiments for the Mexico City area, the northeastern United States, and other regions, together with laboratory studies, have better defined aerosol formation processes, their properties, and their abundances. The studies have shown a higher than expected formation of organic aerosols within the atmosphere, which could potentially have a cooling effect. The research has also demonstrated the influence of aging and composition on aerosol properties, and the ubiquity of

absorbing (warming) aerosols and black carbon in the atmosphere. The information will enable more accurate calculation of aerosol influences on climate through their absorption and scattering of light; results that will ultimately lead to more accurate model estimates of the climatic role of aerosols.

Research Indicates Importance of Anthropogenic Secondary Organic Aerosol.[5] Organic aerosol particles produced within the atmosphere, called "secondary organic aerosol" (SOA), are important to climate because they interact with sunlight and affect the energy balance of Earth's atmosphere. About 90% of secondary organic aerosol is currently believed to arise from the oxidation of natural volatile organic compounds of biological origin. Volatile organic compounds produced by human activity have therefore not been included in most modeling studies that assess the relevance of SOA to climate forcing. However, a recent study examining aerosol production in Mexico City indicates the presence of SOA production pathways not currently accounted for, and suggests that the human-caused sources of SOA are much more important than had been thought. Findings from this study (see Figure 2) show that amounts of SOA produced for any reacted amount of anthropogenic volatile organic compounds are as

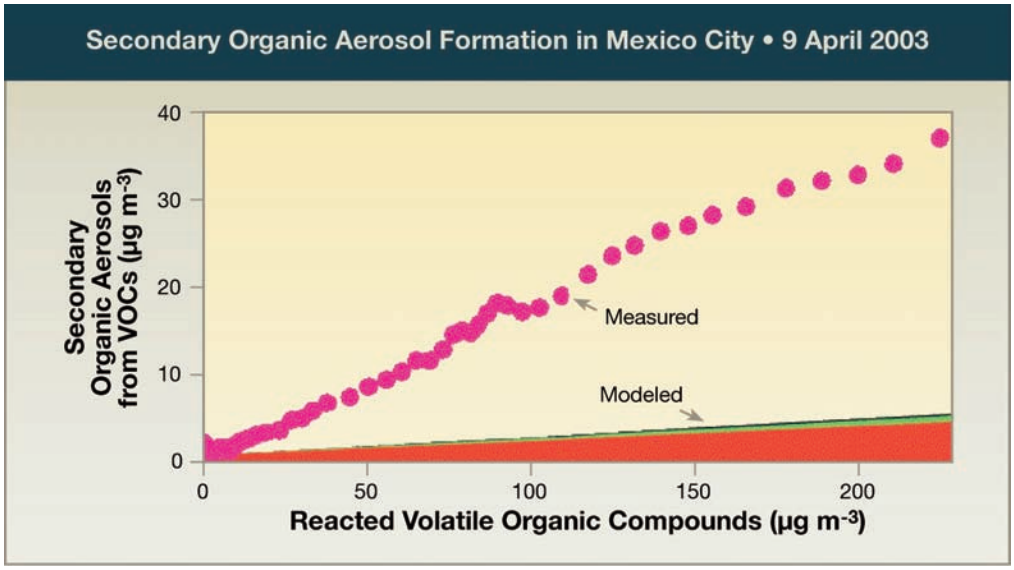
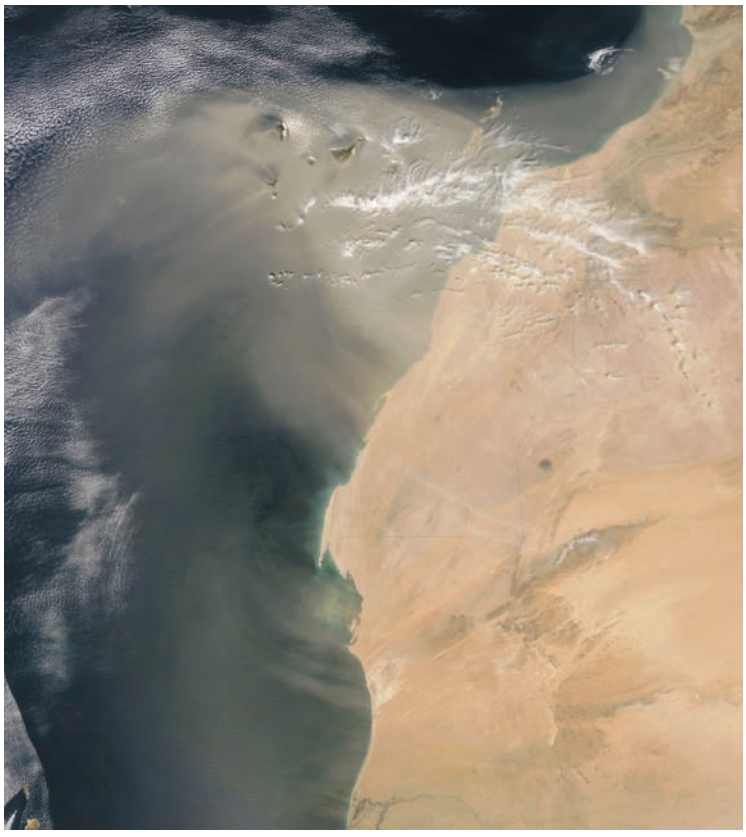


Figure 2: Secondary Organic Aerosol (SOA) Formation in Mexico City. Current state-of-the-art models under-predict the rapid formation of large amounts of SOA. Here, data are shown from Mexico City on 9 April 2003. Solid dots indicate observations and shaded areas indicate the predicted SOA-mass concentration attributed to classes of anthropogenic volatile organic compounds, such as aromatics (red), alkenes (green), and alkanes (black). *Credit: R. Volkamer, University of California, San Diego; J.L. Jimenez, University of Colorado; F. San Martini, National Academy of Sciences; K. Dzepina, University of Colorado; Q. Zhang, SUNY Albany; D. Salcedo, Universidad Autónoma del Estado de Morelos, Cuernavaca, Mexico; L.T. Molina, University of California, San Diego; D.R. Worsnop, Aerodyne Research; and M.J. Molina, University of California, San Diego (redrawn from* **Geophysical Research Letters** *with permission from the American Geophysical Union).*

much as eight times greater than predicted by current models. The research will enable modelers to more accurately represent the atmospheric processes related to SOA, ultimately leading to improved climate projections.

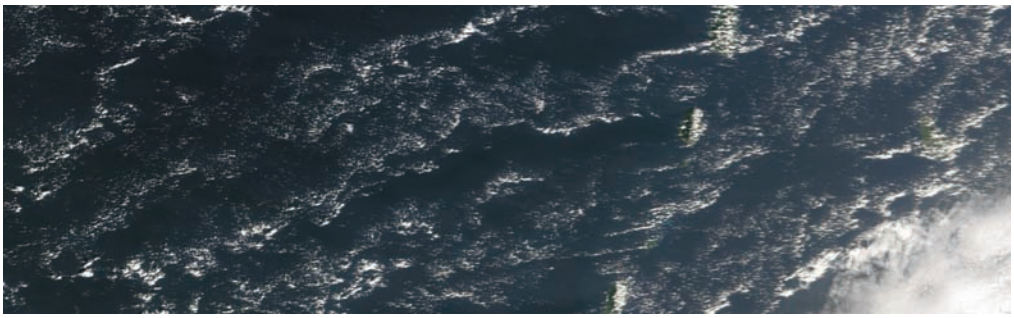
First Analyses from the Gulf of Mexico Climate Study.[8] Several Federal agencies, with significant university, private, and non-profit sector participation, completed a major field mission, the Gulf of Mexico Atmospheric Composition and Climate Study, in early FY 2007 and started analyzing the wealth of data that resulted from the mission. This intensive field study took place in August through October 2006 in the Texas/northwestern Gulf of Mexico region and was focused on providing a better understanding of the sources and atmospheric processes responsible for the formation and distribution of ozone and aerosols in the atmosphere and the influence that these species have on the radiative forcing of climate regionally and globally, as well as their impact on air quality, human health, and regional haze. Rapid synthesis reports on the data were produced within the first few weeks after completion of the mission, an unprecedented turnaround time for communication of the results of a field mission. Early findings are helping to improve the simulation of the radiative forcing of climate change by lower atmosphere ozone and aerosols.

Models Evaluated Using Saharan Dust Storm Data.[9] A large Saharan dust storm raged across the North African desert in March 2006, the largest storm in the last several years. The event was captured by ground-based instruments of the Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) that were deployed in Niamey, Niger, during 2006, as well as by instruments flown onboard the Meteosat-8 geostationary satellite platform, and instruments onboard the Terra and Aqua polar-orbiting satellite platforms. The combination of AMF and satellite observations provides the first well-sampled direct evaluations of the effects of the dust storm on solar and thermal radiation across the atmosphere, allowing researchers to test their understanding of how dust affects the radiant energy budget of the atmospheric column. This information is a key component in computer models that simulate both regional and global weather and climate.



Field and Modeling Studies of Aerosols and Clouds.[10,11,12] A significant but inadequately understood area of climate research involves the effects of aerosol on cloud formation, cloud properties, and cloud lifetimes. An analysis of results from an interagency field experiment, the Cloud Indirect Forcing Experiment, indicates that an increase in aerosol produces higher concentrations of small drops in certain types of maritime clouds. Aircraft and satellite observations of the changes to the maritime clouds show that these microphysical effects result in brighter clouds that have a cooling effect by reflecting more of the incident sunlight back to space. In other CCSP studies, modeling of the effect of carbonaceous (soot-like) aerosol showed a reduction in cloudiness with increasing aerosol amount, as a result of aerosol absorption modifying the heating of the surface and the atmosphere. Finally, another modeling study showed no evidence for aerosol increasing the lifetime of individual cumulus clouds as is usually hypothesized. CCSP researchers also completed a FY 2007 field campaign over the U.S. Southern Great Plains to study the interactions of atmospheric aerosols and fair weather cumulus clouds downstream of a midsize urban area (Oklahoma City), the Cumulus Humilis Aerosol Processing Study (CHAPS). Observations from this campaign will aid in development and evaluation of climate model parameterizations of cloud-aerosol processes. CHAPS involved coordination of experiments between the CCSP Atmospheric Composition and Global Water Cycle Interagency Working Groups.

Phytoplankton Emissions and Cloud Properties over the Southern Ocean.[13] Researchers have long thought that emissions from marine phytoplankton influence aerosols and clouds, but evidence for how this natural process occurs has been scarce. With satellite remote-sensing data and a cloud parcel model, CCSP researchers have shown that over a large area of the Southern Ocean, phytoplankton blooms are correlated in space and time with increases in cloud droplet concentrations and decreases in effective cloud droplet radius. The modeling study showed that the changes in cloud properties could be attributed to the formation of organic aerosol particles arising from the oxidation of a hydrocarbon (isoprene) that is emitted by phytoplankton. This effect seems to act in concert with sulfur emissions from phytoplankton, which have previously received much greater attention.



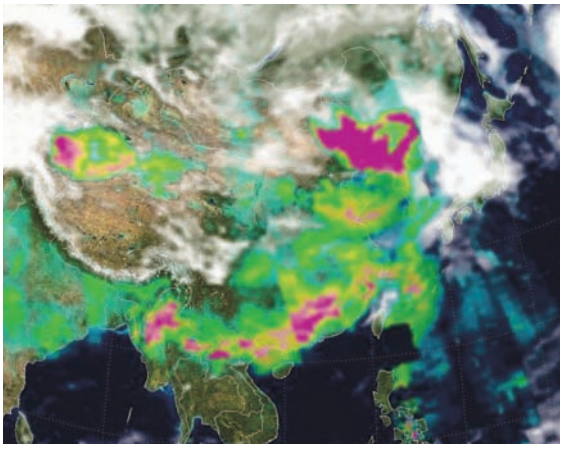
Highlights of Plans for FY 2008

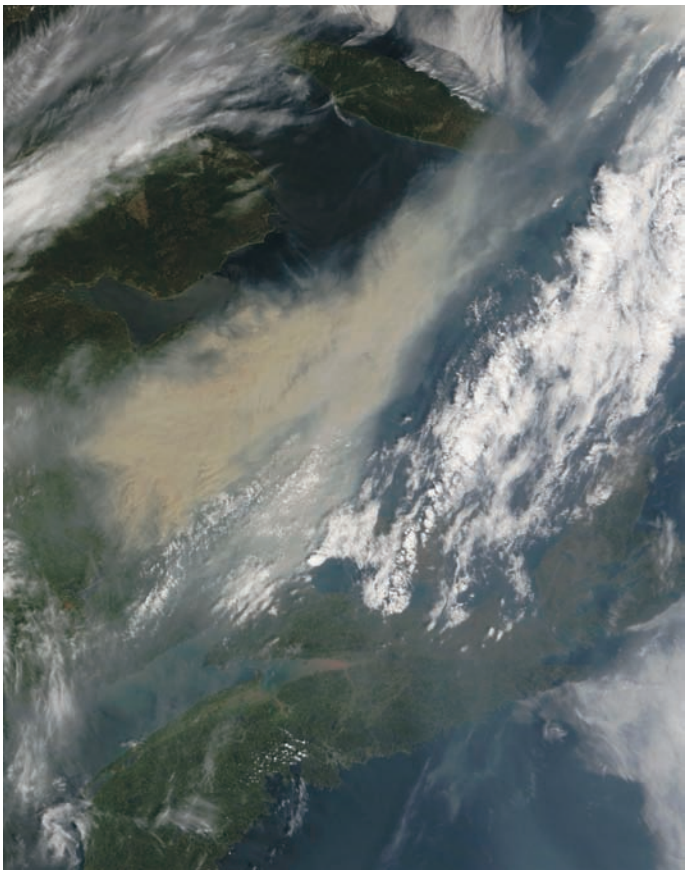
CCSP will continue to gather and analyze information through measurement, modeling, and assessment studies to enhance understanding of atmospheric composition and of the processes affecting atmospheric chemistry. Key research plans for FY 2008 follow.

Tropical Composition, Clouds, and Climate Coupling. CCSP researchers will begin their analysis of data from a FY 2007 field mission in Costa Rica to study how climate is linked to atmospheric composition and clouds in the tropical summer convective wet season. This successful Tropical Composition Cloud and Climate Coupling field mission involved three major aircraft (DC-8, ER-2, WB-57F) making over 20 research flights, using some 60 instruments, involving balloon launches from three locations, and engaging over 250 participants. Analyses will incorporate data from aircraft flights and ground measurements, as well as Aura satellite observations, to address scientific questions related to how clouds, aerosols, and trace gases influence radiative heating in the very active tropical atmosphere.

These activities will address Questions 3.1 and 3.2 of the CCSP Strategic Plan.

International Polar Year Research on Arctic Aerosols and their Connections to Clouds, Radiation, and Ice Melting. The long-range transport of anthropogenic pollution from North America, Europe, and western Asia creates the aerosols associated with the so-called Arctic haze, a phenomenon that recurs every winter and spring. The direct and indirect climate impacts of the aerosols can be quite different in the Arctic compared to elsewhere, because high surface reflections from snow and ice mean that even weakly absorbing aerosol layers can heat the Earth/atmosphere system in the Arctic. As part of International Polar Year (IPY) research, CCSP scientists will conduct field missions to investigate Arctic aerosol/climate connections in this unique environment. Spring and summer measurements from satellites, aircraft, and the surface will be made in collaboration with the larger IPY study POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements, and Models of Climate, Chemistry Aerosols, and Transport). Springtime observations will be made to assess the long-range transport of anthropogenic pollution to the Arctic and its contribution to Arctic Haze, ozone chemistry, and the possible connections between Arctic aerosols





and the melting of polar ice. Summertime observations will be made to assess fire emissions from the boreal forests. Analyses of these measurements will ultimately improve the ability of current models to simulate the influence of anthropogenic pollution and boreal fires on the Arctic atmosphere and climate. In 2008, new aerosol measurements made on the North Slope of Alaska will be used to evaluate model simulations of clouds and aerosol influences in the Arctic.

This activity will address Questions 3.1 and 3.3 of the CCSP Strategic Plan.

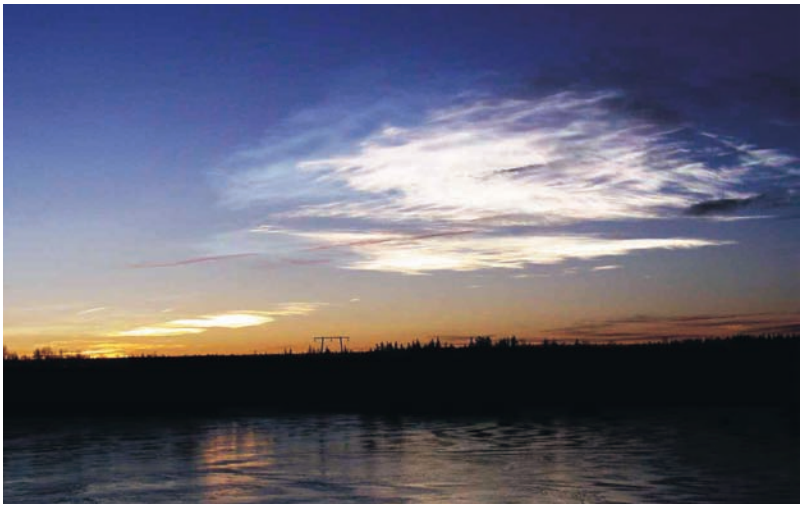
Completion of CCSP Synthesis and Assessment Product 2.3. CCSP researchers will finalize the second phase of CCSP Synthesis and Assessment Product 2.3, *Aerosol Properties and their Impacts on Climate*. The first phase of development of this product was to produce major scientific reviews on the following three topics: dependence of radiative forcing by tropospheric aerosols on aerosol composition in the north Atlantic, Pacific, and Indian Ocean regions; measurement-based understanding of aerosol radiative forcing from remote-sensing observations; and model intercomparison to quantify uncertainties associated with indirect aerosol forcing. The second-phase product will draw upon the scientific information gathered by the development of the Intergovernmental Panel on Climate Change Fourth Assessment Report and the National Research Council review, *Radiative Forcing of Climate Change*. Authors will draw from these community-wide assessments of climate change (and the aerosol-climate topic inclusively) in writing this synthesis and assessment product.

This activity will address Questions 3.1 and 3.2 of the CCSP Strategic Plan.

VOCALS Cloud/Aerosols Field Study. Extensive and persistent layers of stratus clouds occur off the subtropical west coasts of Africa and of North and South America. These cloud decks have a significant impact on Earth's radiation budget. Aerosols, arising from natural processes and from human activity, have important influences on the brightness and persistence of these clouds. The Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS) is planning a field campaign that will study the stratus deck off the Pacific coast of Chile and Peru, using *in situ* and remote aircraft observations, along with satellite and ship-based measurements. Natural and human sources of particles will be observed, as well as the

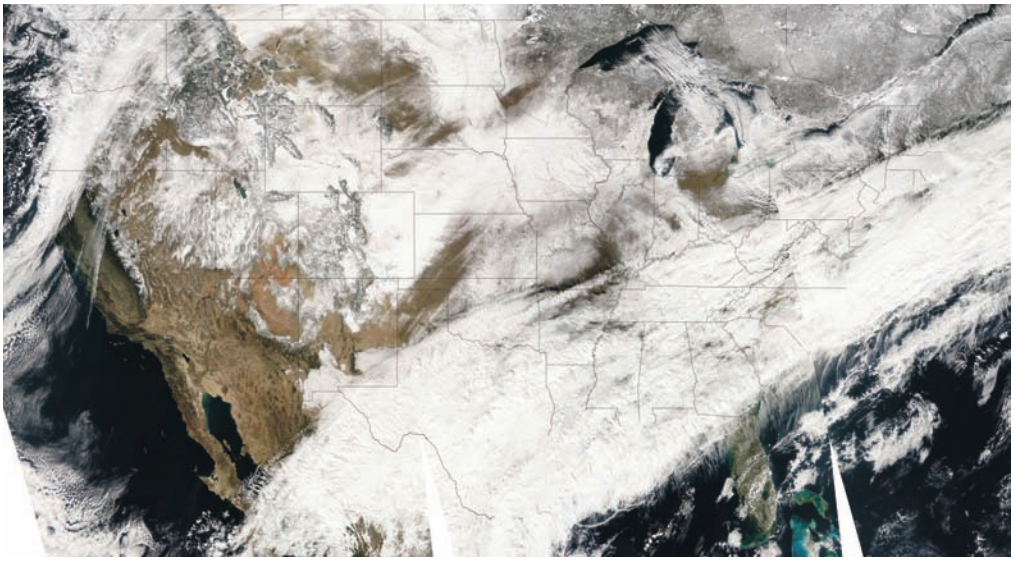
roles these particles play in the determining the brightness and lifetimes of stratus clouds. The VOCALS field campaign is planned for October 2008; preliminary work to simulate the southeast Pacific stratus deck will begin earlier that year.

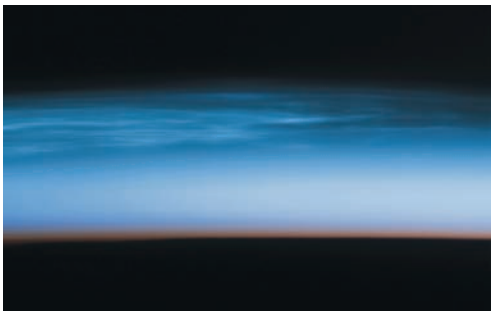
This activity will address Questions 3.1, 3.2, and 3.3 of the CCSP Strategic Plan.



The Ice in Clouds Experiment. The Ice in Clouds Experiment (ICE) will take place in November 2007. The goal of this study is to improve understanding of ice nucleation in the atmosphere. This knowledge will improve the modeling of ice cloud formation, precipitation, and climate effects. The specific objective of ICE is to show that under given conditions, direct measurements of the thermodynamic and kinetic environments of clouds (temperature, humidity, wind) and specific measurable characteristics of the aerosol, including chemical composition, can be used to predict the number of tiny ice particles that are initially seeded by existing atmospheric particles. ICE will use airborne measurements of clouds along with coordinating ground measurements in mountainous locations such as the Front Range of Colorado and Wyoming. Close collaboration between theory, field, lab, and modeling studies will be emphasized.

This activity will address Questions 3.1 and 3.3 of the CCSP Strategic Plan.





Completion of CCSP Synthesis and Assessment Product 2.4. In FY 2008, CCSP researchers will finalize CCSP Synthesis and Assessment Product 2.4, *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*. This report will focus on updating trends in stratospheric ozone, ozone-depleting gases, and ultraviolet exposure, and on improving model evaluations of the sensitivity of the ozone layer to changes in tropospheric composition and climate, along with the implications for the United States. This information is key to ensuring that international agreements to phase out production of ozone-depleting substances are having the expected outcome: recovery of the protective ozone layer.

This activity will address Question 3.4 of the CCSP Strategic Plan.

ATMOSPHERIC COMPOSITION CHAPTER REFERENCES

1) **Velders**, G.J.M., S.O. Andersen, J.S. Daniel, D.W. Fahey, and M. McFarland, 2007: The importance of the Montreal Protocol in protecting climate. *Proceedings of the National Academy of Sciences*, **104**, 4814-4819, doi:10.1073/pnas.0610328104.
2) **Fu**, R., Y. Hu, J.S. Wright, J.H. Jiang, R.E. Dickinson, M. Chen, M. Filipiak, W.G. Read, J.W. Waters, and D.L. Wu, 2006: Short circuit of water vapor and polluted air to the global stratosphere by convective transport over the Tibetan Plateau. *Proceedings of the National Academy of Sciences*, **103**, 5664-5669.
3) **Newman**, P.A., E.R. Nash, S.R. Kawa, S.A. Montzka, and S.M. Schauffler, 2006: When will the Antarctic ozone hole recover? *Geophysical Research Letters,* **33**, doi:10.1029.2005GL025232.
4) **WMO**, 2007: *Scientific Assessment of Ozone Depletion: 2006*. Global Ozone Research and Monitoring Project–Report No. 50. World Meteorological Organization, Geneva, Switzerland, 572 pp.
5) **Volkamer**, R., J.L. Jimenez, F. San Martini, K. Dzepina, Q. Zhang, D. Salcedo, L.T. Molina, D.R. Worsnop, and M.J. Molina, 2006: Secondary organic aerosol formation from anthropogenic air pollution: Rapid and higher than expected. *Geophysical Research Letters*, **33**, L17811, doi:10.1029/2006GL026899.
6) **Quinn**, P.K., T.S. Bates, D. Coffman, T.B. Onasch, D. Worsnop, P.D. Goldan, W.C. Kuster, T. Baynard, J.A. de Gouw, J.M. Roberts, B. Lerner, and A. Stohl, 2006: Impact of sources and aging on submicrometer aerosol properties in the marine boundary layer across the Gulf of Maine. *Journal of Geophysical Research*, **111**, D23S36, doi: 10.1029/2006JD007582.
7) **Gao**, R.S., J.P. Schwartz, K.K. Kelly, D.W. Fahey, L.A. Watts, T.L. Thompson, J.R. Spackman, J.G. Slowik, E.S. Cross, J.-H. Han, P. Davidovits, T.B. Onasch, and D.R. Worsnop, 2007: A novel method for estimating light-scattering properties of soot aerosols using a modified single-particle soot photometer. *Aerosol Science and Technology*, **41**, 125-135.
8) See <esrl.noaa.gov/csd/2006>.
9) **Slingo**, A., T.P. Ackerman, R.P. Allan, E.I. Kassianov, S.A. McFarlane, G.J. Robinson, J.C. Barnard, M.A. Miller, J.E. Harries, J.E. Russell, and S. Dewitte, 2006: Observations of the impact of a major Saharan dust storm on the Earth's radiation budget. *Geophysical Research Letters*, **33**, L24817, doi:10.1029/2006GL027869.
10) **Jiang**, H. and G. Feingold, 2006: Effect of aerosol on warm convective clouds: Aerosol-cloud-surface flux feedbacks in a new coupled large eddy model. *Journal of Geophysical Research,* **111**, doi:10.1029/2005JD006138.
11) **Jiang**, H., A. Xue, G. Teller, G. Feingold, and Z. Levin, 2006: Aerosol effects on lifetime of shallow cumulus. *Geophysical Research Letters*, **33**, doi:10.1029/2006GL026024.
12) **Wilcox**, E.M., G. Roberts, and V. Ramanathan, 2006: Influence of aerosols on the shortwave cloud radiative forcing from North Pacific oceanic clouds: Results from the Cloud Indirect Forcing Experiment (CIFEX). *Geophysical Research Letters*, **33**, L21804, doi:10.1029/2006GL027150.
13) **Meskhidze**, N. and A. Nenes, 2006: Phytoplankton and cloudiness in the Southern Ocean. *Science*, **314**, 5804, doi:10.1126/science.1131779.

2 Climate Variability and Change

Strategic Research Questions

4.1 To what extent can uncertainties in model projections due to climate system feedbacks be reduced?

4.2 How can predictions of climate variability and projections of climate change be improved, and what are the limits of their predictability?

4.3 What is the likelihood of abrupt changes in the climate system such as the collapse of the ocean thermohaline circulation, inception of a decades-long mega-drought, or rapid melting of the major ice sheets?

4.4 How are extreme events, such as droughts, floods, wildfires, heat waves, and hurricanes, related to climate variability and change?

4.5 How can information on climate variability and change be most efficiently developed, integrated with non-climatic knowledge, and communicated in order to best serve societal needs?

See Chapter 4 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Recognizing that the climate system operates seamlessly across time scales, CCSP-supported research encompasses both short-term climate variability and longer term climate change. The connection between higher frequency fluctuations and climate change is the focus of several recent studies on potential relationships between hurricane activity and long-term increases in tropical sea surface temperatures (see discussion in Analysis of Progress Toward Goals section). Interactions among climate system components—for example, involving the atmosphere, oceans, land surface, and cryosphere—are also of fundamental importance to understanding past and projecting future climate changes. Such interactions are vital in explaining past abrupt climate changes, which paleoclimatic evidence suggests have occurred in periods as short as years to decades.[1] An important goal of CCSP research is to assess the likelihood of future abrupt climate changes and to identify the requirements for an early warning system to detect and predict such changes.

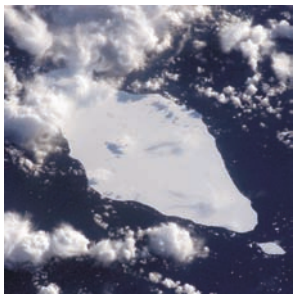
Identifying links and feedbacks among climate system components poses challenges in designing observing systems to monitor the climate system adequately and in constructing models that can properly reproduce past, and confidently project future, climate system behavior. Toward this end, a new generation of climate models that incorporates improved representations of physical processes, increased resolution, and coupling of the different climate system components is being developed within an Earth system modeling framework. Such Earth system models, in combination with global Earth observations, are essential to produce internally consistent maps of atmospheric, oceanic, land surface, and ice conditions, called "Earth system analyses," both in near real-time and retrospectively. The development of such analyses will provide decisionmakers with new tools to visualize the evolving state of the full climate system over the entire planet and provide researchers with the ability to better explain observed changes.

Research within the Climate Variability and Change (CVC) element focuses on two broad, critically important questions to society as defined in the *CCSP Strategic Plan*:

- How are climate variables that are important to human and natural systems affected by changes in the Earth system resulting from natural processes and human activities?
- How can emerging scientific findings on climate variability and change be further developed and communicated in order to better serve societal needs?

More specifically, CVC research addresses the five strategic research questions listed at the beginning of this chapter to achieve the milestones, products, and payoffs described in the *CCSP Strategic Plan*. Cooperative efforts involving CCSP agencies have led to significant progress in addressing all five of the strategic questions articulated in the CVC chapter of the *CCSP Strategic Plan*. The following section highlights some of the major scientific advances achieved during this past fiscal year.

Highlights of Recent Research



CVC research encompasses activities spanning the reconstruction of the climate before the era of modern observing systems (paleoclimate) through model-based projections of future climate change. This section begins with highlights from paleoclimate research published within the past year. Paleoclimate research has proven invaluable in identifying the rates and magnitudes of past climate changes, determining mechanisms that can produce such changes, and helping to constrain estimates of climate system sensitivity in response to changes in radiative forcing. Paleoclimate studies also enable evaluations of climate model performance over far longer time periods and ranges of forcing than would be possible from only modern observational records.

The Pliocene Paradox.[2] During the early Pliocene 3 to 5 million years ago, the intensity of sunlight incident on Earth, the global geography, and the atmospheric concentration of carbon dioxide were similar to today's values, but surface temperatures in polar regions were much higher than today. Continental glaciers were absent from the Northern Hemisphere, and sea level was 25 m higher than at present. This paradox—that the early Pliocene climate was much warmer than today despite similar external forcing—has potential implications for climate stability. It raises the possibility that future melting of glaciers, changes in the hydrological cycle, and a deepening of the upper mixed layer of the ocean could lead to a return toward much warmer conditions similar to the early Pliocene.

Paleoclimate Evidence for Future Ice-Sheet Instability.[3] Conditions during the last interglacial period (129,000-118,000 years ago) as deduced from coral records provide evidence that sea level during this epoch was from 4 to over 6 m above present levels. If current trends in polar warming continue over the next century, climate conditions similar to those of the last interglacial period may result in Arctic and Antarctic ice melt, with sea level rising well beyond current estimates.

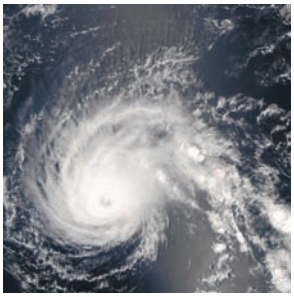
High-Resolution Paleoclimate Records.[4] Research on marine fossils suggests that waters in the central Gulf of California were especially warm during the Medieval Warm Period from approximately AD 900 to1160. A present-day relationship exists between warmer sea surface temperatures in the northern Gulf and more intense development of the North American monsoon in Arizona and New Mexico. Increased monsoonal rainfall during the Medieval Warm Period has also been found in Florida and the Indian Ocean. Increased solar radiance is considered as a possible forcing mechanism.

Reconstructions of Streamflow in the Upper Colorado and South Platte River Basins.[5] Measurements from moisture-sensitive trees in Colorado have been used to extend streamflow records in the Upper Colorado and South Platte River basins back 300 to 600 years, significantly augmenting river gage records. The results indicate that the 20th-century climate is not representative of the range of hydrological extremes due to natural climate variability. For example, multi-year drought events more severe than the 1950s drought occurred as recently as the 19th century. Water managers are now using the paleo-streamflow reconstructions to better

estimate the potential range of natural hydroclimatic variability in the Upper Colorado and South Platte River basins.

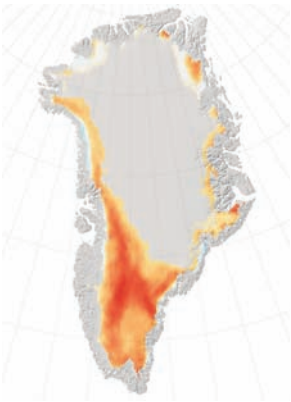
Estimated Climate Sensitivity Constrained by Temperature Reconstructions over the Past Seven Centuries.[6] Climate sensitivity, defined as the equilibrium response of global mean surface temperature to a doubling of carbon dioxide, is an important indicator of the potential for future global warming. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report gives a 5 to 95% range of climate sensitivity of 2 to 4.5°C, with a most probable value of 3.0°C. Some studies suggest, however, the possibility of much higher sensitivities, at or above 8°C. A recent study examines the plausibility of such high sensitivities by using an energy balance model forced by solar, volcanic, and greenhouse gases. This model is used to simulate paleoclimate reconstructions of Northern Hemisphere temperatures over the past 7 centuries. The method involves determining the climate sensitivities that yield simulations in best agreement with proxy reconstructions. After accounting for the uncertainties in temperature reconstructions and estimates of past external forcing, the analysis suggests that the most likely range of climate sensitivity is 1.5 to 6.2°C, and that higher climate sensitivities are inconsistent with paleoclimate evidence.

Studies within the era of modern climate observations are helping to illuminate interactions among climate system components, as well as the connections between longer term climate changes and short-term weather and climate phenomena, including extreme events like hurricanes.



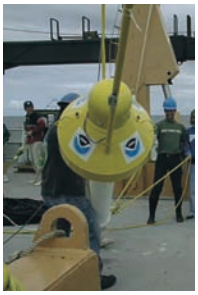
Climate Variability and Change and Hurricanes.[7,8,9,10,11,12,13] There is observational evidence of an increase in intense hurricane activity over the North Atlantic Ocean since around 1970 that is correlated with increasing tropical Atlantic sea surface temperatures. Climate model simulations indicate that sea surface temperature changes in the Atlantic and Pacific tropical cyclone development regions during the 20th century have significant contributions from anthropogenic forcing as well as natural variability. Evidence for changes in tropical cyclone activity outside the Atlantic is mixed, however, with results varying with the ocean basin, period of record, data set, and analysis technique. Because of these and other issues, the reliability

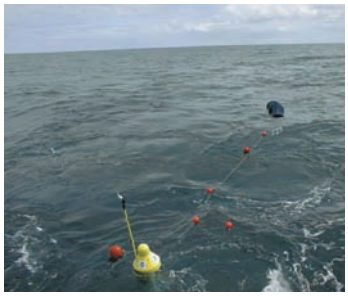
of existing data sets for tropical cyclone trend detection has been questioned. There is general agreement on the need for further work to improve the quality of historical tropical cyclone data sets.



Advances in Detecting Ice Sheet Changes.[14,15,16] Studies applying sensitive gravimetric measurements show net decreases over recent years in the mass of the Greenland and Antarctic Ice Sheets. These reductions appear to be due to increased melting around the ice margins and widespread acceleration in the seaward flow of outlet glaciers. Because of the implications for the rate of sea-level rise, key challenges for future research are to refine further the accuracy of direct observations of ice sheet changes and to improve understanding and modeling of the processes contributing to these changes.

Interannual and Decadal Variability in Ocean Heat Content.[17,18,19] The global ocean has approximately one thousand times the heat capacity of the atmosphere, so monitoring ocean heat content is of fundamental importance to detect and understand changes in the Earth's heat balance. While observations show a general increase in the global ocean heat content over the past half-century, amounting to over 80% of the total heat gain of the climate system, there is large uncertainty due to deficiencies in the historical record of ocean temperature in the Southern Hemisphere. Moreover, the decadal signals are complicated by substantial multi-year fluctuations caused by volcanic activity and/or short-term climate variations such as El Niño. For the recent decade 1993 to 2003, when spatial coverage of measurements improved, enhanced ocean warming accounts for about one-half of global sea-level rise, due to thermal expansion of seawater. Global coverage from 60°S to 60°N of upper ocean temperature was achieved in 2004 by the Argo float project, and Argo data indicate that ocean heat content was approximately constant for the period 2004 to 2006. A significant challenge for understanding the climate system is to correctly represent the interannual to decadal variability of ocean heat content in ocean models.

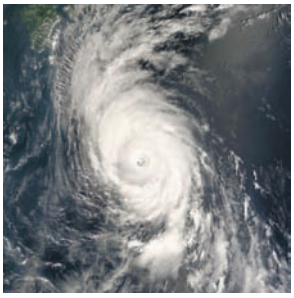




Vegetation-Climate Feedback.[20,21] Understanding the present-day relationships between climate and the ranges of plant species is key to both interpret past changes in plant distributions and to assess the effects of potential future climatic changes on ecosystems. CCSP researchers are conducting analyses that provide direct comparisons of the geographic distributions of temperature, moisture, and bioclimatic parameters with

the ranges of ecoregions and key plant species in North America. Two new volumes of the *Atlas of Relations between Climatic Parameters and Distributions of Important Trees and Shrubs in North America* explore the influence of climate on woody species and ecoregions in Alaska and on ecoregions of North America as defined by three different approaches. The data presented in these volumes are being employed to interpret the climatic changes associated with geologic records of ecosystem changes over the past 20,000 years in North America. These data also provide the basis for modeling potential changes in ecosystems that would occur under a range of future climate change scenarios.

North American Monsoon Data Analysis and Modeling.[22,23,24] Data collected during the North American Monsoon Experiment (NAME 2004) were used in global and regional data analysis and forecast experiments at the NOAA National Centers for Environmental Prediction (NCEP) to test their impact on operational climate products. The NAME 2004-enhanced soundings appear to have a significant beneficial influence on NCEP's operational analyses, particularly over the core monsoon area and in regions where uncertainties are largest. Analyses from the NAME Model Assessment Project show that current models are capable of simulating the general evolution of a summer precipitation maximum near the core monsoon region. Important differences in the monthly evolution and diurnal cycle of precipitation generated by the models were also found, including significant delays of up to a full month in monsoon onset compared to observations. A special issue of *Journal of Climate* published in 2007 includes 22 papers on scientific progress resulting from NAME 2004.



Ozone Increases in the Antarctic Middle Stratosphere.[25,26] An increase in summer ozone concentrations in the Antarctic middle stratosphere has been seen in satellite measurements over the last 2 decades, and its general characteristics have been replicated in a computer model that includes interactive coupling of chemical and meteorological processes. The model yields a summer increase because of changes in polar stratospheric winds that are forced by radiative perturbations associated with the much larger ozone decreases in the lower Antarctic stratosphere. The model findings provide an important evaluation of coupled chemistry-climate models and increase confidence in our ability to make future projections. Other modeling research has shown that warming of the tropical troposphere due to increased greenhouse gases may accelerate the circulation of the stratosphere and thus alter the global distribution of ozone.

Pollution Darkened China's Skies.[27] Records from more than 500 weather stations across China for the years 1954 to 2001 indicate China has darkened over the past half-century. On the other hand, in the most comprehensive study to date of overcast

versus cloud-free days in China, researchers have found that cloud cover has been decreasing for the past 50 years. Less cloud cover, regardless of its cause, should have resulted in more solar radiation reaching the surface. Surprisingly, though, the data show that both solar radiation and pan evaporation decreased in most parts of China by 1.9% (3.1 Wm^{-2}) and 2.2% (39 mm) per decade, respectively. Combined with evidence from other studies of decreased sunshine duration, reduced visibility or clearness, and elevated aerosol optical depth, it appears that air pollution produced a fog-like haze, which reflected and absorbed radiation from the sun and resulted in less solar radiation reaching the surface, despite concurrent upward trends in cloud-free skies over China.

CVC research also encompasses the development and application of climate models of varying complexity. These models are used to understand past climate variations, help explain causes of current climate conditions, and improve short-term climate predictions as well as projections of future climate change.

Mountain Snowpack Projected to Decline.[28] A global climate model with an embedded downscaling scheme predicts that regional mountain snowpack will decline by up to 50 to 80% in many regions of the globe over the next century in response to a scenario of increasing greenhouse gas concentrations in the atmosphere. Previous studies with regional climate models have suggested similar reductions for selected regions and decades in the 21st century. Now, for the first time, a global climate model provides global estimates of snowmelt with 5-km spatial resolution for the period 1980 to 2100. To achieve this resolution, a physically based downscaling scheme was added to the Community Climate System Model (CCSM) that is fully interactive with the atmosphere and land components of the CCSM. Snowpack is most sensitive to spatial resolution because of its dependence on both temperature and precipitation, both of which also depend on surface elevation.

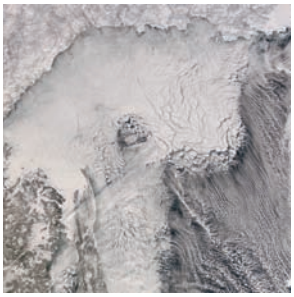
Reducing Uncertainties in Projections of the Thermohaline Circulation.[29] The ocean thermohaline circulation (THC) plays an important role in Earth's climate by transporting heat from low latitudes. Changes in the THC and, in particular, a shutdown of this circulation due to large freshwater input at high latitudes, have been identified as a likely candidate for explaining some past rapid climate changes. A recent study applied a suite of climate models to examine how the THC may respond to additions

of freshwater in the North Atlantic Ocean that could accompany future climate change. In response to expected levels of freshwater input, the models yield generally similar amounts of THC weakening over the next 100 years, on the order of 30% on average, and none of the models simulated a complete shutdown during this period.

Identifying Robust Responses to Anthropogenic Climate Forcing.[30,31] Analyses of climate model simulations generated for the IPCC Fourth Assessment Report have identified several highly reproducible hydrological and atmospheric circulation responses to past and projected future climate forcing. Examples of these robust responses include strong subtropical drying; weakening of large-scale tropical circulations, including an east-west wind pattern over the tropical Pacific known as the Walker circulation; and a poleward expansion of a north-south tropical wind pattern known as the Hadley circulation. A study of the hydrological cycle response shows that, contrary to conventional wisdom, nearly all of the models generate positive cloud feedback, indicating that in these models changes in clouds are amplifying the amount of global warming.

IPCC Model Analyses and Evaluation.[32,33,34,35,36,37,38] Substantial efforts were devoted to develop and analyze the model runs for the IPCC Fourth Assessment Report. Numerous publications describing the National Center for Atmospheric Research CCSM, the NOAA Geophysical Fluid Dynamics Laboratory CM2, and the NASA Goddard Institute for Space Studies EH models are now available. All models are consistent in projecting global warming in the 21st century in response to anthropogenic forcing. The models also include improved El Niño Southern Oscillation (ENSO) characteristics but still have trouble depicting many aspects of ENSO variability and its effects on climate in North America and elsewhere. Generally, only a few models are able to successfully replicate monsoon precipitation patterns. These deficiencies represent fundamental challenges that will need to be addressed in future climate models.

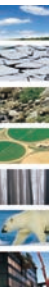
Highlights of Plans for FY 2008



Development of a Permafrost Monitoring Network. Climate projections by coupled atmosphere-ocean global circulation models suggest significant environmental changes will occur in the Arctic during the next 80 years. Given the large potential impacts, and the significant uncertainty in the model projections, the U.S. Department of the Interior is developing a long-term permafrost monitoring network on Federal lands in northern Alaska; this network contributes to the Global Terrestrial Network for Permafrost and the Global Climate Observing System. Analysis of data acquired thus far by the monitoring network suggests that permafrost temperatures on the western

half of the Arctic Coastal Plain in Alaska may have warmed several degrees Celsius between 1980 and 2005.

This activity will address Goals 1 and 4 and Questions 4.3 and 4.5 of the CCSP Strategic Plan.



Yukon River Basin: An Arctic Benchmark. A developing consortium of U.S. and Canadian Federal, state, and provincial agencies, university scientists, and tribal organizations is initiating a major campaign to understand and predict climate-induced changes to the air, water, land, and biota within the Yukon River Basin (YRB). The consortium will implement a prototype environmental monitoring and research strategy that links air, water, soil, and forest information to understand changes in carbon and energy budgets across the Arctic, boreal, and Arctic Ocean systems. This collaborative scientific campaign, using the YRB and adjacent coastal ocean as a representative landscape unit, will provide a benchmark for tracking and understanding changes occurring throughout the Arctic and subarctic region.

This activity will address Goals 1, 2, and 4 and Questions 4.3, 4.4, 6.4, and 7.1 of the CCSP Strategic Plan.

Field Experiment to Improve Understanding of Southeast Pacific Climate Processes. The Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study - Regional Experiment (VOCALS-REx) is planned for October and November 2008. This international field experiment is designed to better understand physical and chemical processes central to the climate system of the Southeast Pacific (SEP) region. The climate system of the SEP involves tightly coupled, but poorly understood, interactions among the ocean, atmosphere, and land. VOCALS-REx will focus on interactions among clouds, aerosols, marine boundary layer processes, upper ocean dynamics and thermodynamics, coastal currents and upwelling, large-scale subsidence, and regional diurnal circulations to the west of the Andes mountain range (see Figure 3). Multidisciplinary intensive observational data sets will be obtained during VOCALS-REx from several platforms including aircraft, research vessels, and a surface land site. An intensive observational period will take place during October and November, when the extent of stratocumulus over the SEP is at its greatest, the southeast trade winds are at their strongest, and the coupling between the upper ocean and the lower atmosphere is at its tightest.

This activity will address Goals 1 and 2 and Questions 3.1 and 4.2 of the CCSP Strategic Plan.

Constructing a Satellite-Era Reanalysis of the Coupled Ocean-Atmosphere System. A national capacity for integrated Earth system analysis is being developed that extends beyond current attempts to map individual components of the Earth system separately. Achieving this capability requires parallel advancements in coupled Earth system

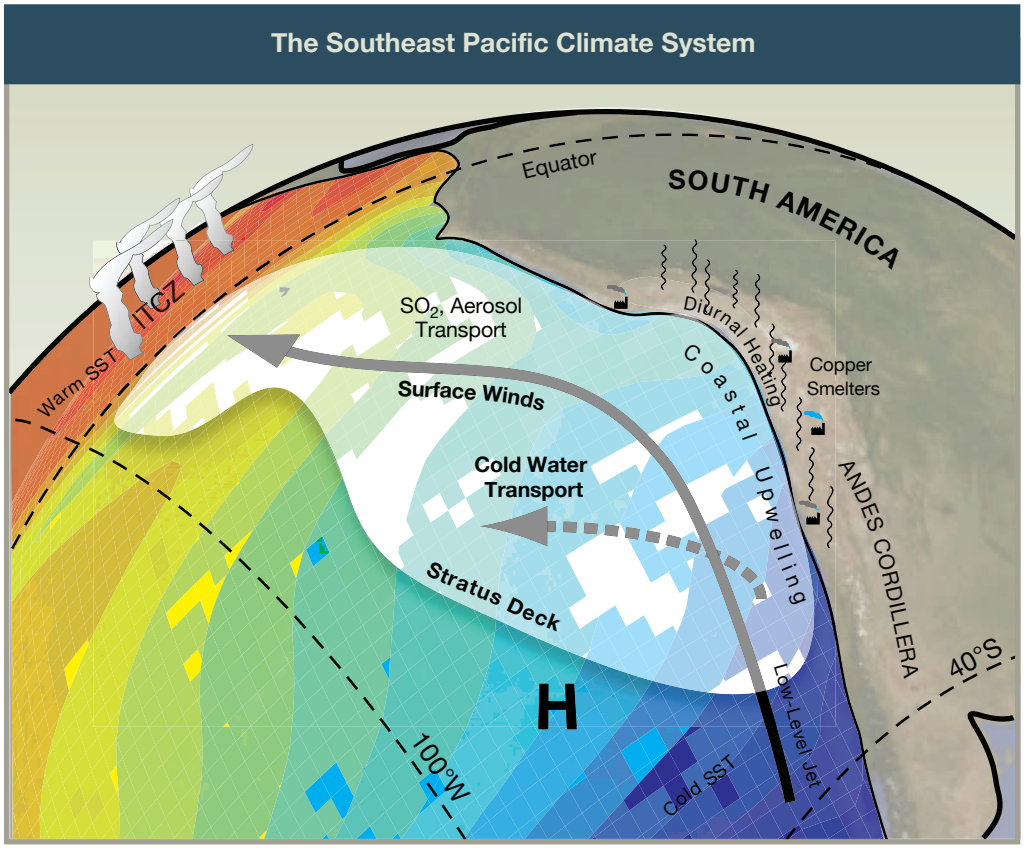
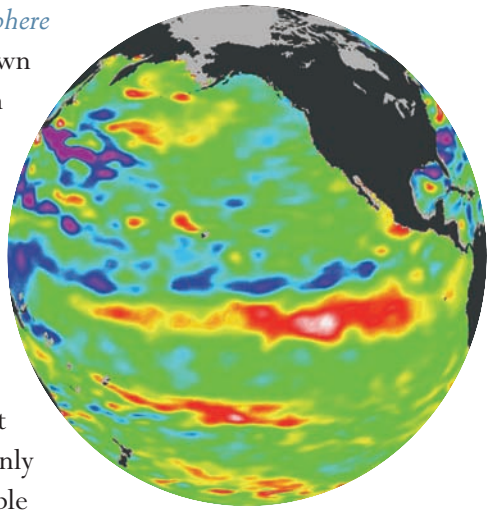


Figure 3: The Southeast Pacific Climate System. Schematic view of the coupled ocean-atmosphere-land system in the vicinity of the southeast Pacific. The interactions among clouds, aerosols, coastal upwelling and currents, upper ocean dynamics, and regional circulations influenced by the Andes are poorly understood and not well modeled, and yet these interactions over the southeast Pacific affect regional and global climate. Surface winds, faced with the Andes barrier, flow parallel to the coast and bring deep, nutrient-rich waters to the surface. These cold waters, aided by an air mass made stable in part by effects of the Andes, help support the largest and most persistent subtropical sheet of stratus and stratocumulus clouds on the planet. This cloud deck, affected by aerosols from both natural and human sources, helps in turn to maintain cool ocean waters beneath. A field campaign, VOCALS, is planned in 2008 to obtain measurements to better understand this complex system and to provide a basis for model improvements. *Credit: R. Wood, University of Washington.*

modeling, and considerable progress is being made in this latter arena, particularly with the adoption by the research and operational forecasting communities of a common Earth system modeling framework. A coupled ocean-atmosphere model is currently in operational use, and during 2008 this model will serve as the basis for beginning the first attempt to create a reanalysis of the coupled ocean-atmosphere system dating back to the start of the satellite era (1979) through 2007. Development of a coupled ocean-atmosphere analysis capability will also support intensified efforts to improve the monitoring and understanding of changes in the ocean thermohaline circulation.

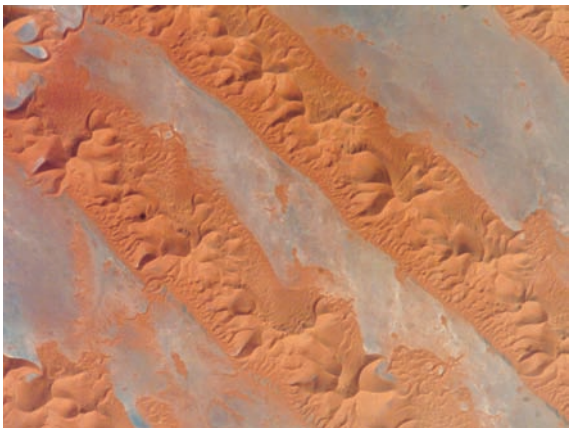
This activity will address Goals 1 and 3 and Questions 4.2, 4.4, and 4.5 of the CCSP Strategic Plan.



Creating a Historical Reanalysis of the Atmosphere of the 20th Century. Recent research has shown the feasibility of using modern data assimilation techniques together with observations of sea-level pressure to produce, for the first time, a global analysis of tropospheric weather patterns at 6-hour temporal resolution that extends over the entire 20th century. Production of this historical reanalysis will be initiated in 2008, with the goal of at least doubling the length of current reanalysis records, which now extend back only until 1948. This historical reanalysis will enable researchers to address such questions as the range of natural variability of high-impact events like floods, droughts, hurricanes, and extratropical cyclones, and how ENSO and other climate modes alter these events. A century-long reanalysis will also help to clarify the origins of climate variations that produced major societal impacts and profoundly influenced policies, including the 1930s "Dust Bowl" drought and the prolonged cool, very wet period in the western United States early in the 20th century that led to over-allocation of Colorado River water through the 1922 Colorado Compact.

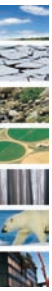
This activity will address Goals 1 and 3 and Questions 4.2, 4.4, and 4.5 of the CCSP Strategic Plan.

Drought in Coupled Models Project. A new, multi-agency activity will support research into the physical and dynamical mechanisms of drought and the mechanisms through which drought may change as climate changes. Relevant issues include the role of the



seasonal cycle in drought, the impacts of drought on water supplies, and the distinction between drought as a transient phenomena and drying produced by long-term changes in a region's water balance. A broad range of model simulations will be analyzed and evaluated in this effort, including multi-model simulations of 20th-century climate, model projections of future climate, paleoclimate simulations of the last glacial maximum, and seasonal model prediction data sets. The objective is to increase community-wide diagnostic research into the physical mechanisms of drought and to evaluate drought simulations by current models. This effort will lead to more robust evaluations of model projections of drought risk and severity, and to a better quantification of the uncertainty in such projections.

This activity will address Goals 1 and 3 and Questions 4.1, 4.2, 4.4, and 5.1 of the CCSP Strategic Plan.



CLIMATE VARIABILITY AND CHANGE CHAPTER REFERENCES

1) **NRC**, 2002: *Abrupt Climate Change: Inevitable Surprises.* National Academy Press, Washington, DC, USA, 230 pp.
2) **Fedorov**, A.V., P.S. Dekens, M. McCarthy, A.C. Ravelo, P.B. deMenocal, M. Barreiro, R.C. Pacanowski, and S.G. Philander, 2006: The Pliocene paradox (Mechanisms for a permanent El Niño). *Science*, **312**(5779), 1485-1489, doi:10.1126/science.1122666.
3) **Overpeck**, J.T., B.L. Otto-Bliesner, G.H. Miller, D.R. Muhs, R.B. Alley, and J.T. Kiehl, 2006: Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science*, **311**, 1747-1750, doi:10.1126/science.1115159.
4) **Barron**, J.A. and D. Bukry, 2007: Solar forcing of Gulf of California climate during the past 2000 years suggested by diatoms and silicoflagellates. *Marine Micropaleontology*, **62**, 115-139.
5) **Woodhouse**, C. and J.J. Lukas, 2006: Multi-century tree-ring reconstructions of Colorado stream flow for water resource planning. *Climatic Change*, **78**, 293-315, doi:10.1007/s10584-006-9055-0.
6) **Hegerl**, G.C., T.J. Crowley, W.T. Hyde, and D.J. Frame, 2006: Climate sensitivity constrained by temperature reconstructions over the past seven centuries. *Nature*, **440**(7087), 1029-1032, doi:10.1038/nature04679.
7) **Webster,** P.J., G. Holland, J. Curry, and H.-R. Chang, 2005: Changes in tropical storm number, duration, and intensity in a warming environment. *Science*, **309**(5742), doi:10.1126/science.1116448.
8) **Emanuel**, K., 2006: Climate and tropical cyclone activity: a new model downscaling approach. *Journal of Climate*, **19**, 4797-4802.
9) **Hoyos**, C.D., P. Agudelo, P. Webster, and J. Curry, 2006: Deconvolution of the factors leading to the increase in global hurricane intensity. *Science*, **312**(94), doi:10.1126/science.1123560.
10) **Kossin**, J.P., K.R. Knapp, D.J. Vimont, R.J. Murnane, and B.A. Harper, 2007: A globally consistent reanalysis of hurricane variability and trends. *Geophysical Research Letters*, **34**(4), L04815, doi:10.1029/2006GL028836.
11) **Santer**, B.D., T.M.L. Wigley, P.J. Gleckler, C. Bonfils, M.F. Wehner, K. Achuta Rao, T.P. Barnett, J.S. Boyle, W. Brüggemann, M. Fiorino, N. Gillett, J.E. Hansen, P.D. Jones, S.A. Klein, G.A. Meehl, S.C.B. Raper, R.W. Reynolds, K.E. Taylor, and W.M. Washington, 2006: Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academies of Science*, **103**(38), 13905-13910, doi: 10.1073/pnas.0602861103.
12) **Landsea,** C.W., B.A. Harper, K. Hoarau, and J.A. Knaff, 2006: Can we detect trends in extreme tropical cyclones? *Science*, **313**(5786), 452-454, doi:10.1126/science.1128448.
13) **Wu**, M.C., K.H. Yeung, and W.L. Chang, 2006: Trends in western North Pacific tropical cyclone intensity. *EOS Transactions of the American Geophysical Union*, **87**(48), 537.
14) **Velicogna**, I. and J. Wahr, 2006: Measurements of time-variable gravity show mass loss in Antarctica. *Science,* **311**, 1754-1756, doi:10.1126/science.1123785.
15) **Rignot**, E. and P. Kanagaratnam, 2006: Changes in the velocity structure of the Greenland Ice Sheet. *Science,* **311**, 986-990, doi:10.1126/science.1121381.
16) **Luthcke**, S.B., H.J. Zwally, W. Abdalati, D.D. Rowlands, R.D. Ray, R.S. Nerem, F.G. Lemoine, J.J. McCarthy, and D.S. Chinn, 2006: Recent Greenland ice mass loss by drainage system from satellite gravity observations. *Science,* **314**, 1286-1289, doi:10.1126/science.1130776.
17) **Levitus**, S.J., I. Antonov, and T.P. Boyer, 2005: Warming of the world ocean, 1955-2003. *Geophysical Research Letters,* **32**, L02604, doi:10.1029/2004GL021592.
18) **Willis**, J., D. Roemmich, and B. Cornuelle, 2004: Interannual variability in upper-ocean heat content, temperature, and thermosteric expansion on global scales. *Journal of Geophysical Research*, **109**, C12036, doi:10.1029/2003JC002260.
19) **Roemmich**, D. and 15 co-authors, 2006: Global warming and sea-level rise. *WCRP Workshop on Understanding Sea Level Rise and Variability, Paris, June 6-9, 2006*.
20) **Thompson**, R.S., K.H. Anderson, L.E. Strickland, S.L. Shafer, R.T. Pelltier, and P.J. Bartlein, 2006: *Atlas of Relations between Climatic Parameters and Distributions of Important Trees and Shrubs in North America – Alaskan Species and Ecoregions*. USGS Professional Paper 1650-D, 342 p.

CLIMATE VARIABILITY AND CHANGE CHAPTER REFERENCES (CONTINUED)

21) **Thompson**, R.S., K.H. Anderson, R.T. Pelltier, S.L. Shafer, and P.J. Bartlein, 2007: *Atlas of Relations between Climatic Parameters and Distributions of Important Trees and Shrubs in North America – Ecoregions of North America*. USGS Professional Paper 1650-E, CD-ROM.

22) **Mo**, K.C., R.W. Higgins, E. Rogers, and J. Wollen, 2007: Influence of the North American Monsoon Experiment 2004 enhanced soundings on NCEP operational analyses. *Journal of Climate*, **20(9)**, 1821-1842, doi:10.1175/JCLI4083.1.

23) **Gutzler**, D.S., H.K. Kim, R.W. Higgins, H.M.H. Juang, M. Kanamitsu, K. Mitchell, K. Mo, P. Pegion, E. Richie, J. Schemm, S. Schubert, Y. Song, and R. Yang, 2005: The North American Monsoon Model Assessment Project: Integrating numerical modeling into a field-based process study. *Bulletin of the American Meteorological Society*, **86**, 1423-1436.

24) **Mo**, K.C., J.E. Schemm, H. Kim, and W.R. Higgins 2006: Influence of initial conditions on summer precipitation simulations over the United States and Mexico. *Journal of Climate*, **19**, 3640-3658.

25) **Stolarski**, R.S., A.R. Douglass, M. Gupta, P.A. Newman, S. Pawson, M.R. Schoeberl, and J.E. Nielsen, 2006: An ozone increase in the Antarctic summer stratosphere: A dynamical response to the ozone hole. *Geophysical Research Letters*, **33**, L21805, doi:10.1029/2006GL026820.

26) **Eichelberger**, S.J. and D.L. Hartmann, 2005: Changes in the strength of the Brewer-Dobson Circulation in a simple AGCM. *Geophysical Research Letters*, **32**, L15807, doi:10.1029/2005GL022924.

27) **Qian**, Y., D.P. Kaiser, L.R. Leung, and M. Xu, 2006: More frequent cloud-free sky and less surface solar radiation in China from 1955 to 2000. *Geophysical Research Letters*, **33**, L01812, doi:10.1029/2005GL024586.

28) **Ghan**, S.J. and T. Shippert, 2006: Physically based global downscaling: Climate change projections for a full century. *Journal of Climate*, **19**, 1589-1604.

29) **Stouffer**, R.J., J. Yin, J.M. Gregory, K.W. Dixon, M.J. Spelman, W. Hurlin, A.J. Weaver, M. Eby, G.M. Flato, H. Hasumi, A. Hu, J.H. Jungclaus, I.V. Kamenkovich, A. Levermann, M. Montoya, S. Murakami, S. Nawrath, A. Oka, W.R. Peltier, D.Y. Robitaille, A. Sokolov, G. Vettoretti, and S.L. Weber, 2006: Investigating the causes of the response of the thermohaline circulation to past and future climate changes. *Journal of Climate,* **19**, 1365-1387.

30) **Vecchi,** G.A., B.J. Soden, A.T. Wittenberg, I.M. Held, A. Leetmaa, and M.J. Harrison, 2006: Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing. *Nature*, **441**, 73-76, doi:10.1038/nature04744.

31) **Held**, I. and B. Soden, 2006: Robust responses of the hydrological cycle to global warming. *Journal of Climate*, **19**, 5686-5699.

32) **Kiehl**, J.T., C.A. Shields, J.J. Hack, and W.D. Collins, 2006: The climate sensitivity of the Community Climate System Model Version 3 (CCSM3). *Journal of Climate*, **19**, 2584-2596.

33) **Schmidt**, G.A., R. Ruedy, J.E. Hansen, I. Aleinov, N. Bell, M. Bauer, S. Bauer, B. Cairns, V. Canuto, Y. Cheng, A. DelGenio, G. Faluvegi, A.D. Friend, T.M. Hall, Y. Hu, M. Kelley, N.Y. Kiang, D. Koch, A.A. Lacis, J. Lerner, K.K. Lo, R.L. Miller, L. Nazarenko, V. Oinas, Jan Perlwitz, J. Perlwitz, D. Rind, A. Romanou, G.L. Russell, M. Sato, D.T. Shindell, P.H. Stone, S. Sun, N. Tausnev, D. Thresher, and M.S. Yao, 2005: Present-day atmospheric simulations using GISS ModelE: Comparison to *in situ*, satellite, and reanalysis data. *Journal of Climate*, **19**, 153-192.

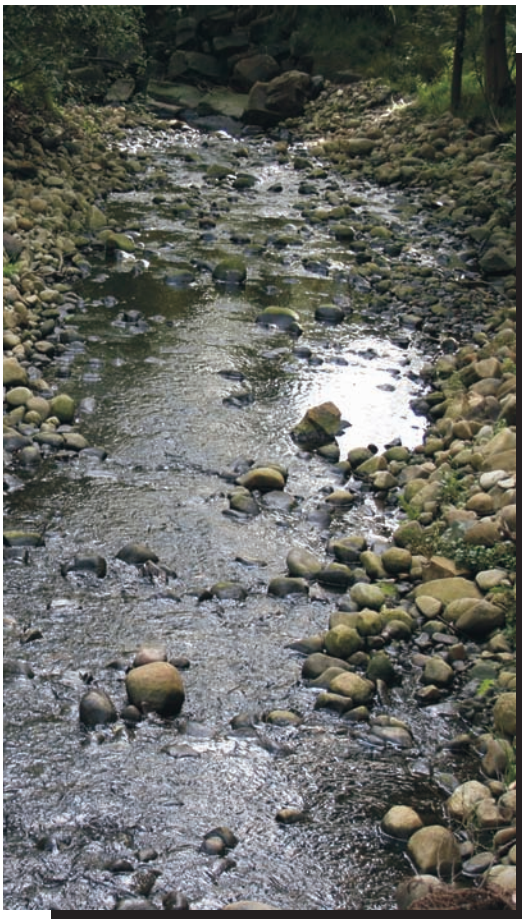
34) **Knutson** T.R., T.L. Delworth, K.W. Dixon, I.M. Held, J. Lu, V. Ramaswamy, M.D. Schwarzkopf, G. Stenchikov, and R.J. Stouffer, 2006: Assessment of twentieth-century regional surface temperature trends using the GFDL CM2 coupled models. *Journal of Climate*, **19**, 1624-1651.

35) **Cook**, K.H. and E.K. Vizy, 2006: Coupled model simulations of the West African Monsoon System: Twentieth and twenty-first century simulations. *Journal of Climate*, **19**, 3681-3703.

36) **Annamalai**, H., K. Hamilton, and K.R. Sperber, 2007: South Asian Summer Monsoon and its relationship with ENSO in the IPCC AR4 Simulations. *Journal of Climate*, **20(6)**, 1071-1092.

37) **Joseph**, R. and S. Nigam, 2006: ENSO evolution and teleconnections in IPCC's twentieth century climate simulations: Realistic representation? *Journal of Climate*, **19**, 4360-4377.

38) **Achuta Rao**, K. and K.R. Sperber, 2006: ENSO simulation in coupled ocean-atmosphere models: Are the current models better? *Climate Dynamics*, **27**, 1-15.



3 Global Water Cycle

Strategic Research Questions

5.1 What are the mechanisms and processes responsible for the maintenance and variability of the water cycle; are the characteristics of the cycle changing and, if so, to what extent are human activities responsible for those changes?

5.2 How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

5.3 What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

5.4 What are the consequences over a range of space and time scales of water cycle variability and change for human societies and ecosystems, and how do they interact with the Earth system to affect sediment transport and nutrient and biogeochemical cycles?

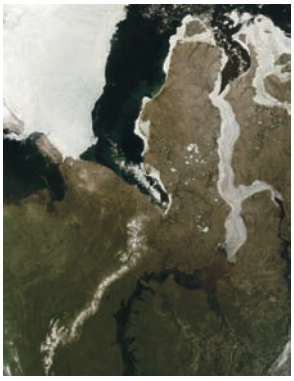
5.5 How can global water cycle information be used to inform decision processes in the context of changing water resource conditions and policies?

See Chapter 5 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

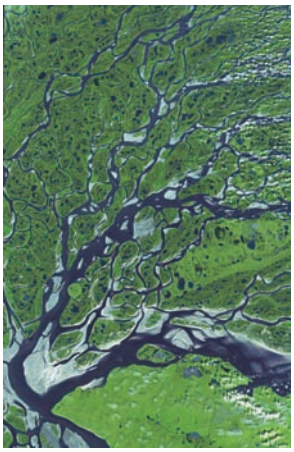
The global water (and energy) cycle plays a critical role in the functioning of the Earth system. Through complex interactions, the global water cycle integrates the physical, chemical, and biological processes that sustain ecosystems and influence climate and related global change. Inadequate understanding of the water/energy cycle is one of the key sources of uncertainty in climate prediction and climate change projections. Clouds, precipitation, and water vapor play important roles in feedbacks that are not well represented in many climate models. These processes alter surface and atmospheric heating and cooling rates, leading to adjustments in atmospheric

circulation and precipitation patterns. Improved understanding of these processes will be essential to develop options for responding to the consequences of water cycle variability and change. For assessing the impacts of global and regional climate change on human societies, industrial and economic systems, and natural and managed ecosystems, water is considered a more rigid or critical constraint or limiting factor than temperature. To address these issues, the CCSP Global Water Cycle (GWC) element expends considerable effort to improve observations, data assimilation, and modeling/prediction systems that in turn deliver the information necessary for decision-support tools and assessments that provide a basis for "best practices" in the management of water resources.

The ultimate goal of water cycle research is to provide a solid foundation for decisions and investments by policymakers, managers, and individuals—be it at the Federal, state, or local level. Achieving this goal requires a program of activities that significantly improves understanding of water/energy cycle processes, incorporates this understanding in an integrated modeling/prediction framework, and tests predictions and data products in real decisionmaking contexts. In order to demonstrate techniques and their effectiveness to potential users, the GWC program also aims to expedite the transfer of science results from the research/experimental realm to operational applications.



Significant progress has been made in the understanding of cloud properties and the direct and indirect effect of aerosols on cloud and precipitation processes through field campaigns such as DOE's Cloud and Land Surface Interaction Campaign (CLASIC), and the multi-agency North American Monsoon Experiment and African Monsoon Multidisciplinary Analyses. Comprehensive satellite monitoring of water cycle parameters such as global precipitation and cloud structure in storm systems and hurricanes (with TRMM) and soil moisture and water bodies (with GRACE) as well as atmospheric profiles of temperature and humidity, and land/ocean surface parameters (Terra, Aqua) have resulted in integrated data sets and improved models of the Earth system. The incorporation of research results in models has led to better simulations of and prediction capabilities for hydroclimatic variables. Multi-model and ensemble modeling techniques developed by the NOAA Climate Prediction Program for the Americas have led to improved seasonal predictions of both the atmospheric and terrestrial hydrological cycle. Techniques have also been developed by USDA, DOI/USGS, and the DOI Bureau of Reclamation, in collaboration with NOAA, NASA, EPA, and DOE, among others, for the downscaling of seasonal precipitation forecasts to temporal scales consistent with the input requirements for agricultural management and conservation planning decision-support tools. Experimental seasonal hydrological prediction systems have been developed that use multiple climate forecast model products and empirical tools to "force" land/hydrological prediction models.

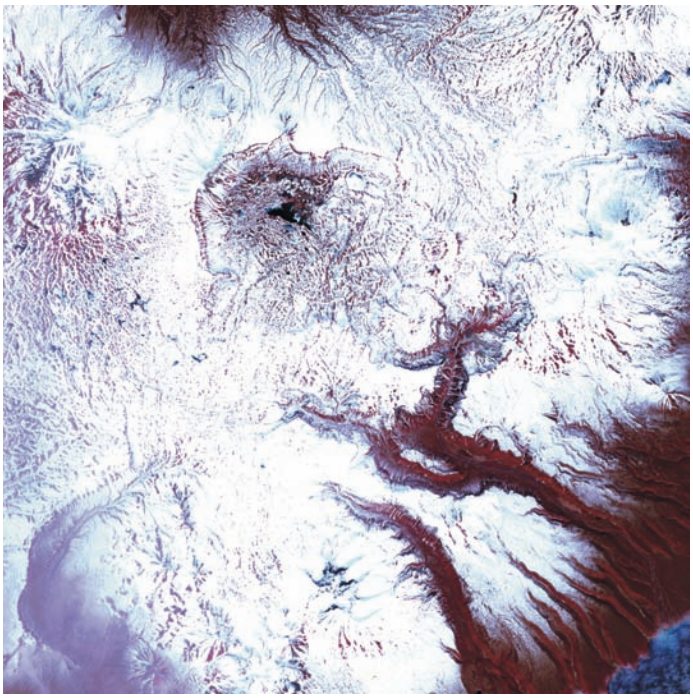


Highlights of Recent Research

Selected highlights of recent research supported by CCSP-participating agencies follow. These research results address the strategic research questions on the global water cycle identified in the *CCSP Strategic Plan*, as well as the goals of said plan.

Reducing Uncertainty in the Predictions/Projections of Climate Change, and in the Global and Regional Water/Energy Cycle.[1] An evaluation of of two modeling approaches, the multi-scale modeling framework (MMF) and the traditional Community Atmospheric Model (CAM), compared the models' simulations with observations. The evaluation showed that distributions of cloud fraction, precipitation intensity, and downwelling solar radiation flux at the surface from the MMF run were more consistent with observations than those from the CAM run (see Figure 4). This is attributed to the improved representation of convective (e.g., thunderstorm) clouds in the MMF compared to the conventional climate model.

Water Cycle over High Latitudes and Polar Regions.[2,3] Consistent with evidence of warmer temperatures, earlier spring green-up of vegetation and longer growing seasons at high latitudes, the atmospheric water cycle over polar regions shows a trend toward an earlier transition from winter to summer moisture recycling patterns during spring over North America and Europe. This conclusion is supported by findings from the Gravity Recovery and Climate Experiment (GRACE) gravity anomaly satellite, and other observations showing a thinning of the Greenland ice sheet and accelerated ice discharge. Model projections of future climate with double and triple atmospheric carbon dioxide concentrations suggest a general increase in precipitation in high-latitude river basins driven by increased transport of moisture into the basins, and higher rates of evaporation driven by rising temperature.



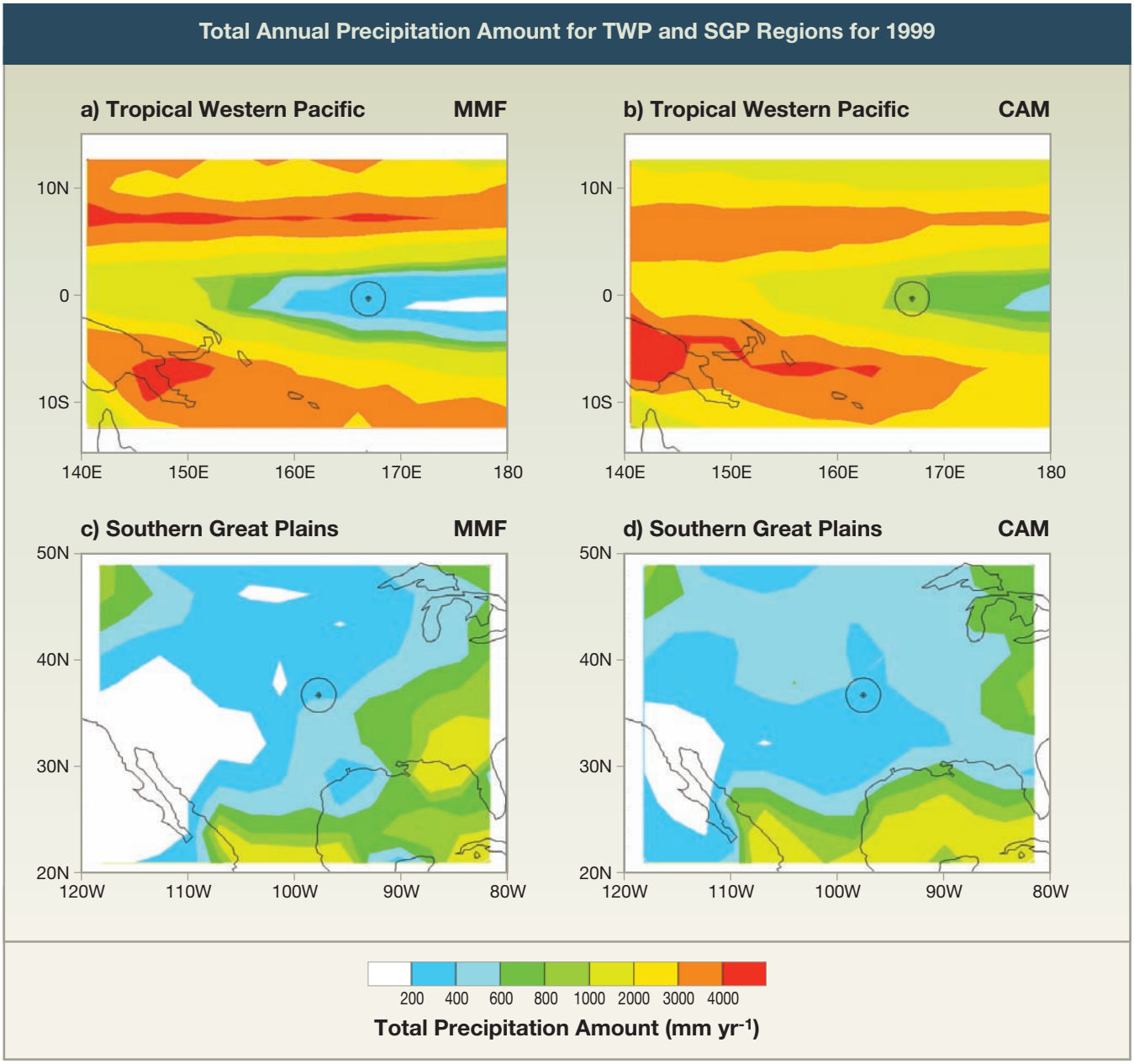
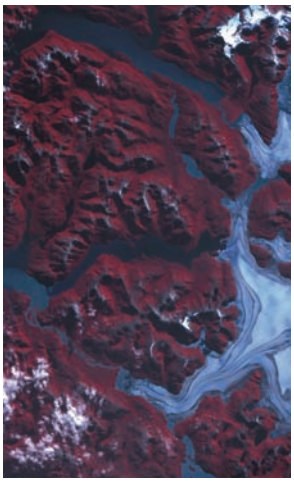


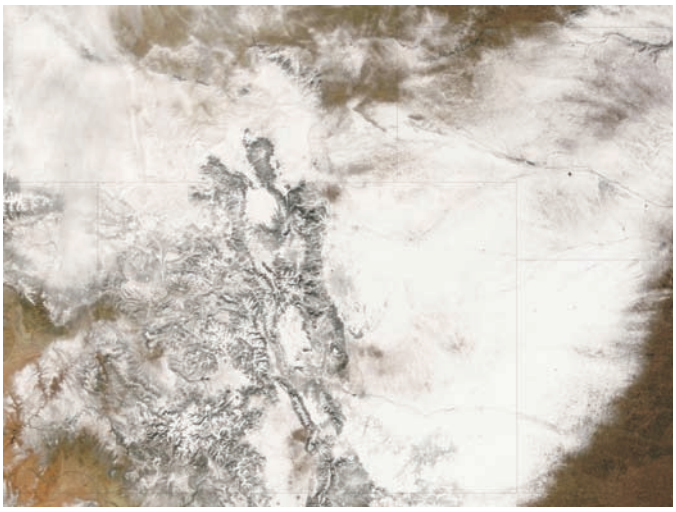
Figure 4: Total Annual Precipitation Amount for Tropical Western Pacific and Southern Great Plains Regions for 1999. Total annual precipitation amount (mm) as predicted by MMF (a,c) and CAM (b,d) for the Tropical Western Pacific (TWP) and Southern Great Plains (SGP) regions for 1999. Locations of the two Atmospheric Radiation Measurement (ARM) sites are circled. The observed precipitation amounts are 358 and 1,031 mm for the TWP and SGP sites, respectively. *Credit: M. Ovtchinnikov, T. Ackerman, and R. Marchand, DOE / Pacific Northwest National Laboratory; and M. Khairoutdinov, Colorado State University (reproduced from the* **Journal of Climate** *with permission from the American Meteorological Society).*



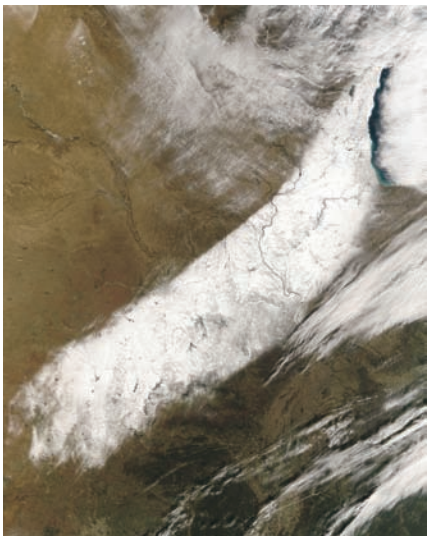
Trajectory Shifts in the Arctic and Subarctic Freshwater Cycle.[4] Manifold changes in the freshwater cycle of the high-latitude lands and oceans have been reported the past few years. A synthesis by researchers of these changes in freshwater sources and in the ocean freshwater storage illustrates the complementary and concurrent pattern and magnitude of these changes over the past 50 years. Increasing river discharge anomalies and excess net precipitation on the ocean contributed about 20,000 km^3 of freshwater to the Arctic and high-latitude North Atlantic oceans from minimal annual rates in the 1960s to maximal rates in the 1990s. Sea ice attrition provided roughly another 15,000 km^3, and glacial melt added about 2,000 km^3. The sum of inputs from these freshwater sources above the long-term average matched the amount and rate at which fresh water accumulated in the North Atlantic during much of the period from 1965 through 1995. The changes in freshwater inputs and oceanic storage occurred in conjunction with the amplifying North Atlantic Oscillation, a large-scale pattern of high and low pressure, and rising air temperatures. Freshwater may now be accumulating in the Arctic Ocean and will likely be transported southward if and when the North Atlantic Oscillation enters a new phase.

Colorado River Basin Water Management.[5] Recent studies of past climate and streamflow conditions have broadened understanding of long-term water availability in the Colorado River, revealing many periods when streamflow was lower than at any time in the past 100 years of recorded flows. Past water management decisions have been based largely on the gage record, and there has been an implicit assumption that there is a single value of the river's average annual flow—about 18.5 km^3 per year—around which interannual flow variations occur. Even though the basin experienced wet and dry periods, river flows and weather conditions were expected to return to a "normal" state, largely defined by the climate of the early and middle 20th century. However, recent reconstructions based on tree rings demonstrate that Colorado River flows occasionally shift into decade-long periods in which average flows are lower, or higher, than the supposed mean value. These reconstructions reinforce the point that the gage record covers only a small subset of the range of natural hydroclimatic variability in the river basin over several centuries. The basin's future hydrology thus may not be reasonably characterized by the gage record alone. That information, along with two important trends—a rapid increase in urban populations in the West and significant climate warming in the region—will require that water managers prepare for possible reductions in water supplies that cannot be fully averted through traditional means. Successful adjustments to these new conditions will require strong and sustained

cooperation among the many entities involved in Colorado River water management and science programs.



Climate-Driven Variability and Trends in Mountain Snowpack in Western North America.[6,7] A recent study applied a regression analysis approach to snowpack and climate station data spanning the period 1960 to 2002 for the western North American region (Oregon, California, Nevada, and Colorado, among others). The study used 1 April snowwater equivalent (SWE) to represent a cumulative, simplified summary of the previous several months' weather: snow deposition, snow melting or ablation, and rain events that may either partially melt snow or be absorbed in the snowpack, increasing SWE. For most snow course locations in the West, the study found that long-term variations in spring SWE are reasonably well explained by summaries of seasonal climate at nearby stations. Day-to-day details of snow accumulation, ablation, and melt are generally of secondary importance, except where correlations between observed and climate-derived SWE are low. During the second half of the 20th century, and likely since 1916, winter and spring warming in the West have reduced spring snowpack at most locations. Increases in precipitation appear to have offset this loss in some places since mid-century, notably in the southern Sierra Nevada mountains, where large increases have occurred. Some of the interannual variability and long-term trends can be explained as a response to variability and change in North Pacific climate, especially as represented by the North Pacific Index (NPI), which responds to the oceanic variations of the El Niño Southern Oscillation and Pacific Decadal Oscillation, which are large-scale patterns of climate variations. However, NPI can only account for about half of the trends in the Pacific Northwest since mid-century (and less elsewhere or from earlier starting points), in rough agreement with modeling results. The remaining portion clearly includes the influence of the warming observed throughout the West, which is largely unrelated to the Pacific climate variability and may well represent human influences on climate. That is, even after accounting for the role of known patterns of climate variability, there is a substantial



downward trend in overall snowpack in the West that is consistent with observed warming. Even a conservative estimate (0.3°C per decade) of the likely future warming rate for the western mountains in winter would, by 2100, move the 0°C isotherm to where the 3°C isotherm now lies: Most of the western mountains would be in the transient snow zone, in which snow accumulates and melts repeatedly during the snow season. In the future, intraseasonal behavior of snowpack will likely change from a steady accumulation to alternating accumulation and loss due to warmer conditions. Simple regression-based methods currently used by water resource planners for forecasting seasonal volumetric streamflow will have to be revised or replaced by more sophisticated methods that can account for the changing role of temperature both in determining the quantity of spring snowpack (the subject of this study) and the rate at which it melts.

Vegetation, Soil Moisture, and Water Table Interactions.[8,9] The fraction of rainfall that recharges groundwater and ends up as streamflow tends to increase as the fraction of land devoted to agriculture decreases. Conversely, when the extent of cultivation increases a greater fraction of rainfall goes into evapotranspiration, potentially driving a long-term drop in groundwater levels. This is true in areas without crop irrigation. Where irrigation taps surface or groundwater, depletions may be even faster. Modeling of the coupled groundwater-surface water-soil vegetation system shows that shallow water tables can be either a sink or source of water relative to surface soil moisture, depending on the balance of infiltration versus evaporation, while deep water tables have little impact on surface fluxes. Thus, intense agriculture can amplify surface water stresses by increasing the propensity of soil moisture to decouple from a depleting water table, particularly during drought conditions.

The Effect of Irrigation on Land Surface Temperatures.[10] As seen from space, the region identified as the Umatilla Ordnance Depot in northeastern Oregon provides a striking example of temperature contrast caused by irrigation and vegetation type. Suited to hot, dry summers and an average annual precipitation of 200 mm, the native plants that grow on the depot use little water. Poplars—fast-growing commercial trees used as inexpensive lumber and pulp for paper—use large amounts of water, making them one of the most heavily irrigated crops in the Columbia River Basin. In nature, poplars grow in wetlands or along riverbanks, where they have access to water, and the commercial poplar plantation is located close to the river for the same reason. Figure 5 shows the difference in water use that distinguishes the two ecosystems.

Irrigation and Land Surface Temperature in Oregon

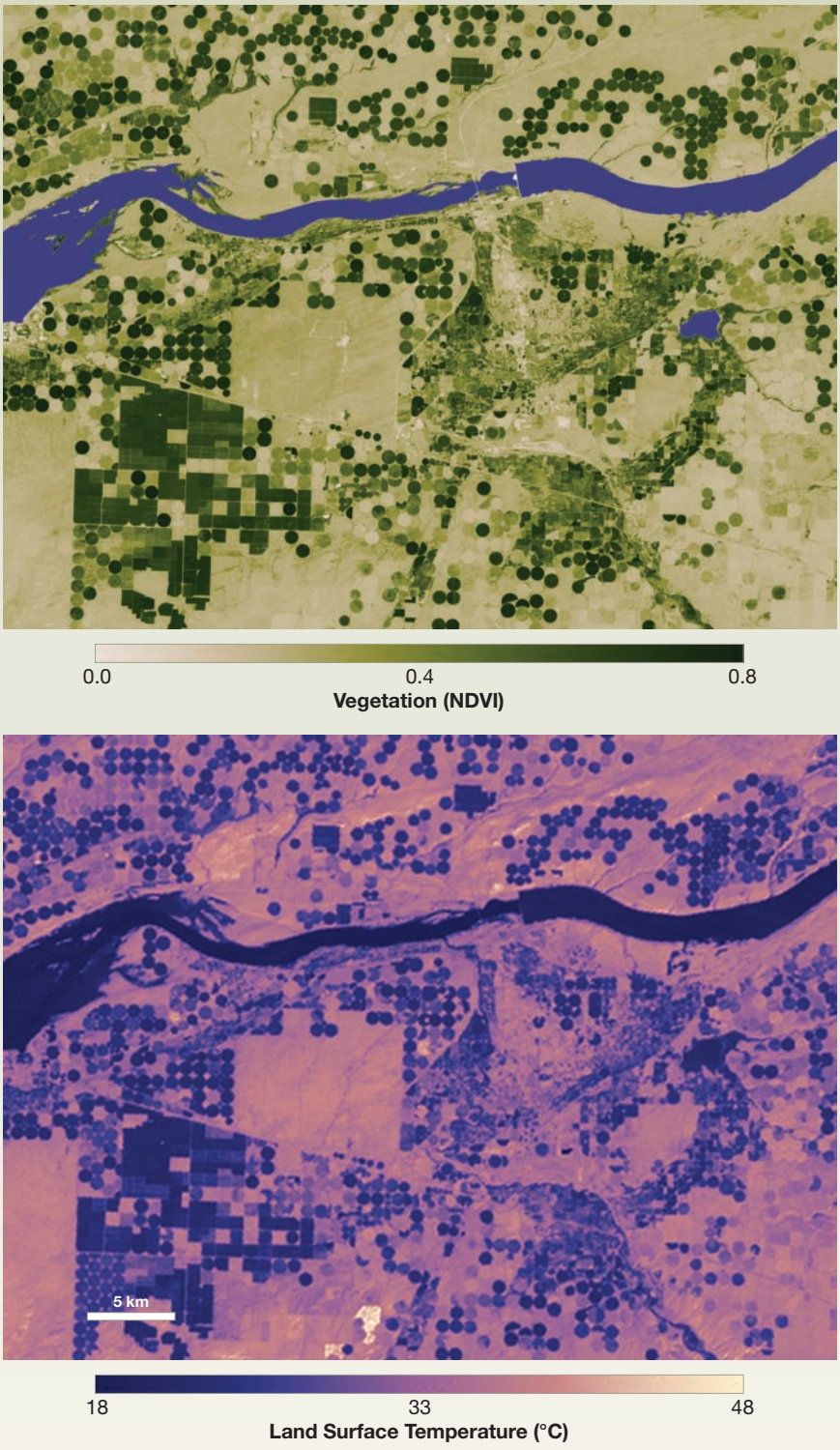
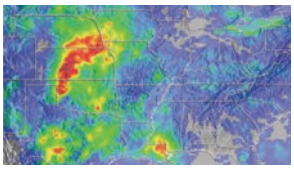


Figure 5: Irrigation and Land Surface Temperature in Oregon. The difference between poplar plantations and native vegetation is illustrated in this pair of satellite images, collected by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite on 27 August 2006. The top panel depicts vegetation index, a measure of the density of plants based on the amount of photosynthesis recorded by the sensor. The availability of water causes the difference between the densely vegetated areas (dark green) and the lightly vegetated areas (light green). The contrast between irrigated and non-irrigated land is also evident in the bottom panel, which shows land surface temperatures measured by the same ASTER instrument. The coolest areas are dark blue, and the warmest pink and yellow. Irrigated crop lands are much cooler than the surrounding native vegetation. In this semi-arid region, the temperature difference is as much as 30°C (54°F), similar to the temperature difference between the Congo Rainforest and the Sahara Desert in Africa. *Credit: J. Allen, NASA / Goddard Space Flight Center (<earthobservatory.nasa.gov>), using data provided courtesy of NASA/GSFC/METI/ERSDAC/ JAROS and the U.S./Japan ASTER Science Team.*



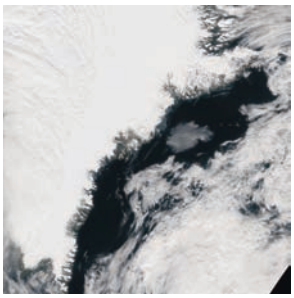
Fifty-Year High-Resolution Global Data Set of Meteorological Forcings for Land Surface and Hydrological Modeling.[11] Understanding variability of the terrestrial hydrological cycle is central to determining the potential for extreme events and its susceptibility to future change. In the absence of long-term, large-scale observations of the components of the hydrological cycle, modeling can provide consistent fields of land surface fluxes and states. To enable such an integrated analysis, researchers have created a global, 50-year, 3-hourly, 1° data set of meteorological forcings that can be used to drive models of land surface hydrology. The data set was constructed by combining a suite of global observation-based data sets with the National Centers for Environmental Prediction-National Center for Atmospheric Research reanalysis. Known systematic errors (biases) in the reanalysis precipitation and near-surface meteorology have been corrected using observation-based data sets of precipitation, air temperature, and radiation, among others. Wind induced undercatch of frozen precipitation is removed using the results of the World Meteorological Organization's Solid Precipitation Measurement Intercomparison. Precipitation is reduced in scale to 1° using statistical relationships developed with the Global Precipitation Climatology Project (GPCP) daily product. Disaggregation in time from daily to 3-hourly is accomplished similarly, using the Tropical Rainfall Measuring Mission (TRMM) 3-hourly real-time data set. Other meteorological variables (downward shortwave and longwave radiation, specific humidity, surface pressure, and wind speed) are downscaled in space while accounting for changes in elevation. The data set was evaluated against the bias-corrected forcing data set of the second Global Soil Wetness Project (GSWP2). The final product can be used to drive models of terrestrial hydrologic and ecological processes for the study of seasonal and interannual variability and for the evaluation of coupled models and other land surface prediction schemes.

Highlights of Plans for FY 2008

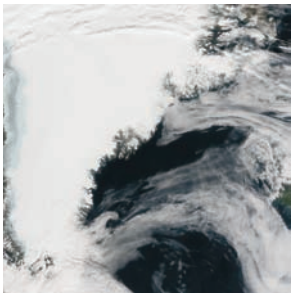
The GWC research element continues to pursue important, long-term priorities. For example, insights into the formation and behavior of clouds and precipitation, including better characterizations of the phase changes of water in clouds and the phases and onset of precipitation, are emerging from field campaigns and model studies and will be promoted in continuing activities. Water vapor and cloud-radiation feedback are considered a critical part of GWC studies that need to be addressed to reduce the uncertainties associated with climate change projections. The predictability of regional precipitation is another topic of vital interest: It will be assessed and better understood by ongoing diagnostic and modeling studies that identify the connections between regional- and global-scale phenomena, land surface conditions such as soil moisture and water table fluctuations, and the interface fluxes of energy and heat between the

atmosphere and the land surface-vegetation-hydrology combination. Preliminary analyses from recent studies show promise of leading to earlier (and more accurate) predictions, improved ability to assess hazards and risks of extremes such as floods and droughts, and more efficient water resource management.

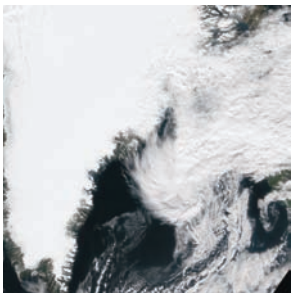
In FY 2008, continuing U.S. and global observations, field campaigns and experiments, improvements to data integration and analysis systems, diagnostic and predictive model development, and applications to decision support systems will be priorities under the CCSP Global Water Cycle program. A fundamental objective is to ensure that observational capability is enhanced and improved, and that the data assimilation and modeling/prediction systems are more reliable and accurate at the point of application. Several promising results from the past years of research will be further explored with an aim to transfer this research knowledge to operational applications that provide societal benefit. Concurrently, a cohesive research strategy will be implemented to improve current deficiencies in understanding of all aspects of the regional and global water cycle. Several science questions remain to be answered, related to warnings of natural hazards and to the impact of global climate change, be it from natural or anthropogenic causes.



The program outlined for FY 2008 will lead to improvements in fundamental research, as well as in the planning and decisionmaking for, and management of, natural and human-made resources—a major aim of the program in addition to its fundamental research goals. A strong effort will continue to focus on major unresolved research issues that will require longer term commitments. To address both research and multi-sectoral applications needs, several initiatives will be launched in FY 2008.



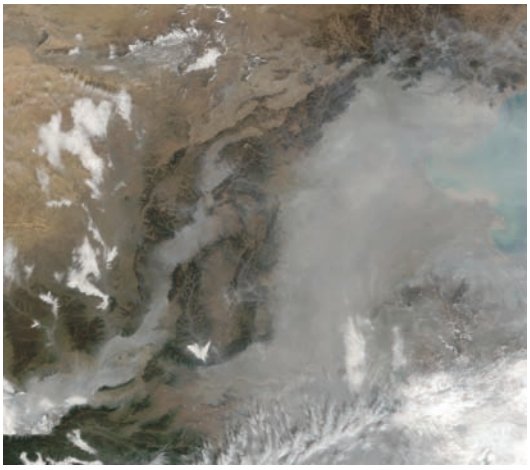
Integration of Space-Based Observations and Land Surface/Hydrology Data Assimilation Systems. The GRACE satellite has demonstrated that large-scale changes in the integrated column water content of the combined atmosphere, land surface (including rivers and reservoirs), soil moisture, and groundwater system compares remarkably well with the changes documented by the Global Land Data Assimilation System (GLDAS). In FY 2008 and beyond, further research investigations will explore whether GRACE, A-Train, and other satellite and ground-based data can be assimilated by the Land Information System (LIS), and/or provide integral closure constraints (and updated process parameterizations) to improve the output products from LIS that can potentially be linked to various decision-support tools and systems involved in the management of water resources, among others. Such an activity could represent initial components of end-to-end capabilities bridging observations, research, modeling, and applications.



This activity will address CCSP Goals 1 and 3 and Questions 5.1, 5.3, 5.4, and 5.5 of the CCSP Strategic Plan.

Integration of Observations, Research, and Modeling.[12,13] The research data from CLASIC will be analyzed in FY 2008 and beyond to address significant uncertainties in climate models particularly related to their representation of clouds and aerosols. The primary goal of CLASIC is to improve understanding of the physics of the early stages of cumulus cloud convection as it relates to land surface influences, and to translate this new understanding into improved representations of coupled surface-atmosphere processes in global and regional climate models. The data from a comprehensive array of measurements from a variety of instrument platforms will be used to characterize the synoptic-scale forcing at the DOE's Atmospheric Radiation Measurement (ARM) Climate Research Facility's (ACRF) Southern Great Plains (SGP) site and to undertake modeling studies to establish the most important relationships between land surface conditions and cumulus cloud characteristics. CLASIC was designated as the core of the Global Water Cycle Interagency Working Group CCSP FY 2007 focus area. The field campaign serves as a prototype for the CCSP focus area. The campaign featured concurrent contributions by NASA, NOAA, and USDA to extend CLASIC's temporal and spatial domain to capture the seasonal time scale and regional processes. The resulting observational framework included ground- and space-based observations, measurements from six airplanes and one helicopter, surface and subsurface hydrologic components, isotopic measurements, CO_2 fluxes, and associated modeling. Planning and operations for CLASIC and DOE's Atmospheric Science Program's Cumulus Humilis Aerosol Processing Study (CHAPS) were coordinated. Scientists from CLASIC and the North American Carbon Program (NACP) Mid-Continent Intensive (MCI) Campaign also coordinated measurement and modeling activities. These campaigns represent the cross-cutting activities of three CCSP science elements—the Global Water Cycle, Atmospheric Composition, and Global Carbon Cycle, respectively.

This activity will address CCSP Goals 1, 2, and 3 and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.



Application of the ARM Mobile Facility to Study the Aerosol Indirect Effects in China. China has exceptionally high aerosol loading with diverse properties whose influence has been detected across the Pacific Rim. The rapid pace of changes in the atmospheric environment over China provides a natural test bed for identifying and quantifying the climatic effects of aerosols. Preliminary analyses of multiple satellite data sets [the Moderate Resolution Imaging Spectroradiometer (MODIS) and the TRMM Tropical Microwave Imager] indicate more complex and unique aerosol indirect effects than are found in relatively cleaner environments. Unfortunately, China is one of the least observed regions, especially in terms of aerosol and cloud properties. To this end, DOE's ARM Mobile

Facility (AMF) will be deployed from 1 January to 31 December 2008 to investigate (1) the mechanisms of the aerosol indirect effects in the region and the roles of aerosols in affecting regional climate and atmospheric circulation with a special focus on the impact of the East Asian monsoon system, and (2) effects of long-range transport of aerosols to the Pacific Rim and the western United States.

This activity will address CCSP Goals 1 and 2 and Questions 5.1 and 5.2 of the CCSP Strategic Plan.

Advanced Ensemble Multi-Model Hydrological Prediction. Efforts will continue to focus on the calibration and validation of research-mode ensemble (multi-model) forecasting techniques for surface and subsurface hydrological parameters, especially on longer seasonal time scales. The objective is to transfer improved hydrological prediction techniques for operational application on the seasonal to interannual time scale. This activity will expand on the recently developed Advanced Hydrological Prediction Service (AHPS) of NOAA's hydrological forecasting system that includes new model calibration strategies, distributed modeling approaches, ensemble forecasting, data assimilation techniques, enhanced data analysis procedures, flood forecast inundation maps, hydrological routing models and multi-sensor precipitation estimates. Data will also be ingested from USGS streamflow observations, gridded multi-sensor precipitation and SWE estimates, and others. New approaches for the remote sensing of precipitation, snow, and other inputs will be integrated into the hydrological forecast operation. AHPS is slated to be fully implemented nationwide in 2013. In parallel, CCSP researchers plan to participate in the further development of the international Hydrological Ensemble Prediction Experiment (HAPEX), which will bring the international hydrological community together with the meteorological community and demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence by emergency management and water resources sectors to make decisions that have important consequences for the economy, and for public health and safety.

This activity will address CCSP Goals 3 and 5 and Questions 5.3 and 5.5 of the CCSP Strategic Plan.

Role of Land Surface Processes in North American Hydroclimate. The feedbacks between soil moisture, vegetation, and precipitation will be investigated in observations and models with the goal of helping to understand whether land surface conditions may be a useful predictor in operational climate prediction at seasonal and sub-seasonal time scales. The behavior of snow variations and vegetation cover will be studied in order

to improve land surface representations in regional climate models. The hydrologic and climatic effects of crop irrigation are not well quantified and not accurately represented in model initialization. Improvements in our understanding of the role of irrigated croplands in North American hydroclimatic regimes and their representation in models will be pursued.

This activity will address CCSP Goals 3 and 4 and Questions 5.3 and 5.4 of the CCSP Strategic Plan.

Continued Development of Tools for the Assimilation of Remote-Sensing Data into Water Quality and Sediment Transport and Erosion Models. Agricultural research activities in the area of land data assimilation systems and model analysis are focused on the efficient integration of ground-based and remote-sensing data into critical resource and conservation practice assessment models. Existing agency research projects are aimed at the sequential assimilation of surface soil moisture retrievals and vegetation indices from microwave and visible remote sensors to constrain crop growth and root-zone water balance models. In FY 2008 and beyond, this work will expand with an emphasis that includes the assimilation of remote-sensing data into distributed water quality and sediment transport and erosion models. Particular attention will be paid to development of data assimilation and modeling capabilities to quantify benefits arising from the adoption of conservation practices within agricultural watersheds.

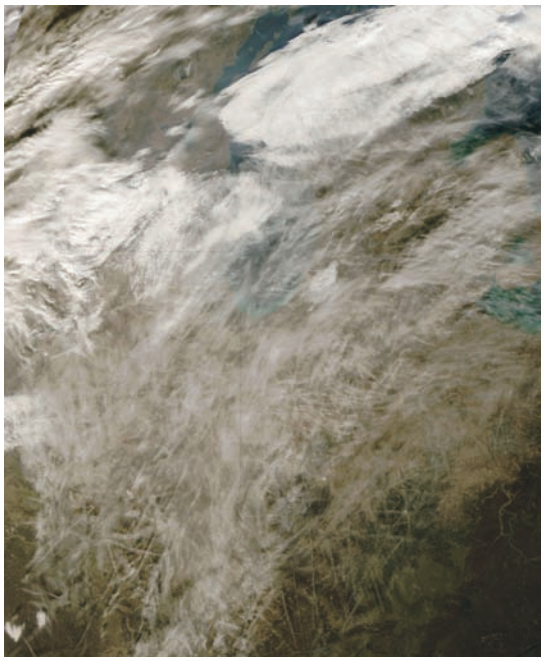
This activity will address CCSP Goals 3 and 5 and Questions 5.3 and 5.5 of the CCSP Strategic Plan.

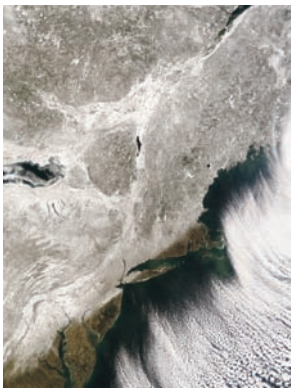
Establishing New Portals Dedicated to Specific Applications of Remote-Sensing Data with On-Line Analysis Capabilities.[14] "Giovanni," the Goddard Earth Sciences Data and Information Services Center (GES-DISC) Interactive Online Visualization and Analysis Infrastructure, was developed to provide researchers with advanced capabilities to perform data exploration and analysis with observational data from the Earth Observing System (EOS) research satellite system. Over the past decade, the central problem with data use has been the multi-step process required to search for the appropriate data files, request the files from a central archive, transfer the files to the scientist's own computing system, extract the relevant data from unfamiliar data formats, and then (finally) analyze the data to investigate the vital research question.

Giovanni eliminates all of the above tedious steps that precede data analysis. The result is a data exploration and analysis environment that facilitates scientific investigation with actual data, allowing rapid comprehension of regional events and increased understanding of interconnected global environmental processes. The Giovanni precursor, the TRMM Online Visualization and Analysis System (TOVAS), successfully demonstrated the basic elements of a system used entirely on the Web. The simplicity of Giovanni enables the creation of portals dedicated to specific applications of remote sensing. The first of such portals will be devoted to "precipitation data for agriculture." Release is expected in FY 2008. An A-Train Data Depot Portal and the Northern Eurasia Earth Science Partnership Initiative portal are also planned for release in the same time frame. The former is expected to be particularly useful because the A-Train, which is a formation of several NASA atmospheric observational missions in the same orbit, allows for nearly simultaneous observations. In the dedicated Giovanni interface, data from these missions will be readily available for multi-parameter comparison and analysis. In FY 2008, a specific effort under the NASA Energy and Water Cycle Study will build a portal in collaboration with the Global Change Master Directory (GCMD) for hydrological networking.

This activity will address CCSP Goals 1, 2, and 3 and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

Upper Tropospheric Water Vapor, Jet Contrails, and Implications for Climate.[15,16] Water vapor in the upper troposphere, while insignificant in the total mass of column water vapor, can have significant effects on climate through the formation of clouds (longwave forcing) or direct absorption of radiation. One study using a radiative transfer model estimated that a 10% increase in upper-tropospheric humidity (UTH) could contribute as much as 1.4 Wm^{-2} of direct radiative forcing. Supersaturation in the upper troposphere can be inferred from the presence of persistent contrails behind jet aircraft, which require humidity above that of ice saturation to form. Supersaturation is critical for understanding the process of ice cloud formation. This process, which is also affected by the presence or absence of aerosols, has implications for the radiative balance of the climate system through its effect on clouds and water vapor. Most global models of the climate system do not permit supersaturation but instead dictate full condensation of all water vapor to maintain a vapor pressure less than 100% over ice at temperatures where only ice exists (typically below -20 to -40°C). Using relative humidity (RH) data from the Atmospheric Infrared Sounder (AIRS) on the Aqua satellite, the annual mean frequency of supersaturation maximizes below the





extratropical tropopause ranges between 10 and 30% of the time. This value is similar to the annual mean potential contrail coverage frequency (which implies RH over ice greater than 100%) reported from European Centre for Medium-Range Weather Forecasts' reanalyses. While these comparisons are good, AIRS RH is not a point-wise measurement and observed supersaturation may not quantitatively define what an air parcel or a cloud/ice nucleus experiences. Further studies of supersaturated conditions from AIRS are being considered that may be able to shed some light on cloud nucleation processes when combined with other satellite sensors. In the future, an updated AIRS retrieval and cloud properties from a suite of sensors flying in formation on NASA's A-Train (such as MODIS on the EOS Aqua satellite and the Cloud Profiling Radar on CloudSat) may be useful to answer important questions about ice nucleation and its global impact, as well as to improve global models in order to examine perturbations to the Earth system. Such studies could also be useful in evaluating the potential implications of aviation on climate.

This activity will address CCSP Goals 1,2,3, and 4 and Questions 5.1, 5.2, 5.3, and 5.4 of the CCSP Strategic Plan.

GLOBAL WATER CYCLE CHAPTER REFERENCES

1) **Ovtchinnikov**, M., T. Ackerman, R. Marchand, and M. Khairoutdinov, 2006: Evaluation of the Multiscale Modeling Framework using data from the Atmospheric Radiation Measurement Program. *Journal of Climate,* **19(9)**, 1716-1729, doi:10.1175/JCLI3699.1.
2) **Dirmeyer**, P.A. and K.L. Brubaker, 2006: Trends in the Northern Hemisphere water cycle. *Geophysical Research Letters*, **33**, L14712, doi:10.1029/2006GL026359.
3) **Rignot**, E. and P. Kanagaratnam, 2006: Changes in the velocity structure of the Greenland Ice Sheet. *Science,* **311**, 986-990, doi:10.1126/science.1121381.
4) **Peterson**, B.J., J. McClelland, R. Curry, R.M. Holmes, J.E. Welsh, and K. Aagaard, 2006: Trajectory shifts in the Arctic and sub-Arctic freshwater cycle. *Science*, **313**, 1061-1066.
5) **NRC**, 2007: *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*. National Academy Press, Washington, DC, USA, 159 pp.
6) **Mote**, P.W., 2006: Climate-driven variability and trends in mountain snowpack in Western North America. *Journal of Climate*, **19**, 6209-6220.
7) **Hamlet**, A., P.W. Mote, M.P. Clark, and D.P. Lettenmaier, 2005: Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate*, **18**, 4545-4561.
8) **Jayawickreme**, D.H. and D.W. Hyndman, 2007: Evaluating the influence of land cover on seasonal water budgets using NEXRAD rainfall and streamflow data. *Water Resources Research*, **43**, W02408, doi:10.1029/2005WR004460.
9) **Miguez-Macho**, G., Y. Fan, C. Weaver, R. Walko, and A. Robock, 2007: Incorporating water table dynamics in climate modeling, Part II: Formulation, validation, and soil moisture simulation. *Journal of Geophysical Research,* **112**, D13108, doi:10.1029/2006JD008112.
10) **Mildrexler**, D.J., M. Zhao, and S.W. Running, 2006: Where are the hottest spots on Earth? *EOS, Transactions, American Geophysical Union*, **87(43)**, 461-467.
11) **Sheffield**, J., G. Goteti, and E.F. Wood, 2006: Development of a 50-year high-resolution data set of meteorological forcings for land surface modeling. *Journal of Climate*, **19**, 3088-3111.
12) See <science.arm.gov/clasic/>.
13) See <asp.labworks.org/>.
14) **Acker**, J.G. and G. Leptoukh, 2007: Online analysis enhances use of NASA earth science data. *EOS, Transactions, American Geophysical Union*, **88**, 14-17.
15) **Gettelman**, A., W.D. Collins, E.J. Fetzer, A. Eldering, F.W. Irion, P.B. Duffy, and G. Bala, 2006: Climatology of upper tropospheric relative humidity from the Atmospheric Infrared Sounder and implications for climate. *Journal of Climate*, **19**, 6104-6121.
16) **Gettleman**, A., E.J. Fetzer, A. Eldering, and F.W. Irion, 2006: The global distribution of supersaturation in the upper troposphere from the Atmospheric Infrared Sounder. *Journal of Climate*, **19**, 6089-6103.

4 Land-Use and Land-Cover Change

Strategic Research Questions

6.1 What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?

6.2 What are the primary drivers of land-use and land-cover change?

6.3 What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?

6.4 How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?

6.5 What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

See Chapter 6 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Land use and land cover affect the global climate system through biogeophysical, biogeochemical, and energy exchange processes. Variations in these processes due to land-use and land-cover change in turn affect local, regional, and global climate patterns. Key processes include uptake and release of greenhouse gases by the terrestrial biosphere through photosynthesis, respiration, and evapotranspiration; the release of aerosols and particulates from surface land-cover perturbations; variations in the exchange of sensible heat between the surface and atmosphere due to land-cover changes; variations in absorption and reflectance of radiation as land-cover changes affect surface reflectance; and surface roughness effects on atmospheric momentum that are land-cover dependent. Human activity can and does alter many of these processes and attributes, but weather and climate, as well as geological and other natural processes, are also important.

For example, land-cover changes such as deforestation and forest fires alter ecosystems and release carbon dioxide, methane, carbon monoxide, and aerosols to the atmosphere. They also change the reflectivity of the land surface which in turn determines how much of the sun's energy is absorbed and thus available as heat, while vegetation transpiration and surface hydrology determine how this energy is partitioned into latent and sensible heat fluxes. At the same time, vegetation and urban structure determine surface roughness and thus air momentum and heat transport.

Land-use and land-cover change studies also provide critical inputs to large-scale vegetation biomass and forest cover assessments that are key components of the carbon cycle. Future land-use and land-cover change goals include very accurate biomass estimates to refine knowledge of carbon storage in vegetation, understanding regional land-use changes that affect biomass, and quantifying linkages and feedbacks between land-use and land-cover change, climate change forcings, climate change, and other related human and environmental components.

Research that examines historic, current, and future land-use and land-cover change, their drivers, feedbacks to climate, and environmental, social, economic, and human health consequences is therefore of utmost importance and often requires interagency and intergovernmental cooperation. One example of a multi-agency effort is the Congo Basin Forest Partnership, which focuses on conserving the second largest tropical rainforest in the world in equatorial Africa. Satellite data are used to map forest extent, determine habitat fragmentation, and enforce conservation laws, and thus minimize greenhouse gas emissions from deforestation. Another example was the North America Land Cover Summit held in September 2006, which explored and encouraged collaboration among institutions and government agencies to advance the development and application of land-cover information in Mexico, the United States, and Canada.[1]

Highlights of Recent Research

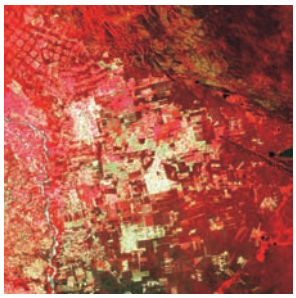
Selected highlights of recent research into land-use and land-cover change issues supported by CCSP-participating agencies follow.

Land-Use and Land-Cover Change Drivers Vary by Region and Geopolitical Events.[2,3] As part of a national assessment of U.S. land-cover change, the USGS recently completed and web-published an analysis of land-cover and land-use change rates for 20 U.S. ecoregions that span 1,650,930 km^2 of the eastern United States. Land-cover extent and changes through time were assessed for ten land-cover types through five time periods: 1973, 1980, 1986, 1992, and 2000. Major findings of this study showed that

eastern U.S. land change was connected primarily to timber harvesting and urban growth, together with a decline in agricultural activity. The observed changes were complex and ecoregion specific. The southern United States is thought to be the largest sink for carbon in the conterminous United States. In a long-term assessment of change, researchers reconstructed an annual land cover of the southern United States from 1860 to 2003 with a spatial resolution of 8 km. The pattern of land-cover change in the southern United States was primarily driven by the change in cropland, including cropland expansion and forest regrowth on abandoned cropland. The net flux of carbon due to land-use change in this region was estimated to be zero from 1980 to 2003; but, from 1860 to 1980, land-use and land-cover change was estimated to have resulted in a net release of 9.4 GtC across the southern United States.

Changes in Eastern Europe due to Socioeconomic and Political Factors following the Breakdown of the Soviet Union.[4] A comparison of land cover in the Polish, Slovak, and Ukrainian Carpathian Mountains in 2000 from Landsat images showed marked differences in forest cover, dominant forest species, and agricultural fragmentation. These differences can largely be explained by socialist forest management. Post-socialist land-cover change was greatest in Ukraine, where there was high agricultural fragmentation and widespread early-successional shrublands indicating extensive land abandonment. The abundance and pattern of arable land and grassland was attributed to land tenure in socialist times and economic transition since 1990. These results suggest that broad-scale socioeconomic and political factors are of major significance for land-cover patterns in Eastern Europe.

Land-Cover Change Detection using MODIS Data for Non-Agricultural Areas of the U.S. East Coast.[5] Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m data are used to form the Normalized Difference Vegetation Index (NDVI), a measure of the photosynthetic capacity of vegetation. Composite NDVI data sets were used to provide automated detection of vegetation change and alarm capability on a 1-year time step for the Albemarle-Pamlico Estuary System region of the U.S. east coast. Vegetation change detection accuracy was assessed for 2002 at 88% with a reasonable balance between change commission errors (22%) and change omission errors (28%). Annual change detection rates across the Albemarle-Pamlico Estuary System over the 2002 to 2005 study period were estimated at 0.7% per annum and varied from 0.4% in 2003 to 0.9% in 2004. Extended regional variations were also readily apparent ranging from 1.6 to 0.1% per annum for the tidal water and mountain ecological zones, respectively. This research included the application of an automated protocol to first filter the MODIS vegetation index data to remove unreliable data values and then estimate the missing data values using a statistical technique to provide high-quality uninterrupted data to support the change detection analysis. The methods and results detailed apply only to non-agricultural areas.



Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in Brazil.[6] Brazil has become a major producer in world soybean markets, with about 10 million hectares currently planted. Cultivation of this crop is rapidly expanding into two Brazilian ecological zones: the savannah or cerrado, and the forested Amazonian region. The climatic consequences of converting forested Amazonian areas into cropland are significant due to their vastly different storage capacities for carbon. There is a need for accurate updated information on the newly expanded agricultural areas in Brazil and the current total production in order to predict contributions to climate forcings from these regions. A method for assessing crop area and retrieving crop condition parameters that can be used to assess crop yields was developed using data from the MODIS instrument onboard the Terra satellite.

Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in the Mid-West United States.[7] Crop type, yield, and land management affect the balance of greenhouse gas fluxes from land cover in the mid-western United States. The magnitude of surface changes such as tillage intensity affects residue cover and thus the moisture and radiation energy balances at the land surface through changes in evaporation and reflectance. However, these distinctions are difficult to assess across landscapes. Agricultural Research Service scientists working in Iowa have developed a method using Landsat Thematic Mapper and EO-1 Hyperion imaging spectrometer data to classify tillage intensity in cropland.

Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in Central America.[8] A methodology has been developed for observing changes in tropical forest cover for large areas using data with high temporal frequency from coarse-resolution satellite imagery. Proportional forest cover change is estimated from multi-spectral, multi-temporal MODIS data that are transformed to optimize the spectral detection of vegetation changes. This methodology has been applied using MODIS data in Central America. Landsat data are also used to record higher detail changes of forest cover in Central America. This work describes the distinct patterns of change from year to year due to land-cover changes resulting from forest clearing, regeneration, and changes in climate. It was found that the ability to detect forest cover change patterns using this methodology was relatively independent of the spatial resolution of the data. Associated model simulations indicated the best metrics for detecting tropical forest clearing and regeneration are the shortwave infrared information from the MODIS data at 500-m resolution. Errors were found to range from 7 to 11% across the time periods of analysis.

Regional Climate Change due to Agricultural and Urban Development in California.[9] In the western United States, large changes in land cover and land use have occurred

over the past century with rapidly expanding urbanization along the Pacific coast, and extensive agricultural development inland. A regional climate model was used by researchers to quantify the differences in surface energy fluxes and atmospheric circulation associated with land-cover changes between approximately 1990 and the present. They showed that irrigated agriculture in California lowered mean and maximum surface air temperatures, while conversion of natural vegetation to urban areas increased ground temperatures. This land-use change pattern resulted in changes in the spatial patterns of air pressure and energy balance causing reduced westerly breezes and increased inland breezes. Overall, conversion of natural vegetation to irrigated agriculture has had a larger effect on California's climate than urban growth up until now, but future projections of increased conversion of irrigated land to urban/suburban development could alter this balance.

Western Wildfires, Land-Cover Disturbance and Response to Climate Warming.[10,11] Wildfire intensity and duration can have a large effect on forest recovery. Scientists from Scripps Institute of Oceanography, the University of California Merced, the USGS, and the University of Arizona compiled a comprehensive database of large wildfires in the western United States since 1970 and compared it with land surface data and hydroclimatic data to show that marked and sudden increases in large wildfire activity in the mid-1980s—including higher frequencies, longer seasons, and longer duration of the fires—were strongly associated with increased spring and summer temperatures and earlier snowmelt. Recent studies in ponderosa pine-dominated forests of northern Arizona have found that intense stand-replacing wildfire converts forests to grasslands and shrublands and converts the land from a CO_2 sink to a source, even 10 years after burning, creating a positive feedback to increasing temperatures. Work emerging from CCSP is contributing to the Joint Fire Science Program, which is attempting to improve understanding of climate controls of wildfire (see Figure 6).

Coconino National Forest, Northern Arizona

Figure 6: Coconino National Forest, Northern Arizona. This photo shows Coconino National Forest 10 years after an intense stand-replacing wildfire. The wildfire converted the site from a dense forest of ponderosa pine to a grassland in which trees have not regenerated. Such a conversion from forest to grass- or shrub-land is common in ponderosa pine forests of the southwestern United States following intense wildfire. The instrument tower measures ecosystem CO_2 flux for comparison with unburned forest. This site was a CO_2 sink 10 years ago, but is now a CO_2 source due to decomposition of organic matter in the soil offsetting photosynthesis by the low leaf area of the grassland. *Credit: M. Montes-Helu, Northern Arizona University.*

National Land Cover Database Available for Use in Climate Models and Assessments.[12] The USGS, on behalf of the interagency Multi-Resolution Land Characteristics Consortium (MRLC), has made available the National Land Cover Database (NLCD 2001) products for the conterminous United States. These products are available for download from the MRLC web site at <www.mrlc.gov>. NLCD 2001 products include 21 classes of land cover, percent tree canopy, and percent urban imperviousness at 30-m resolution derived from Landsat imagery. NLCD 2001 will support a wide variety of users, institutional sectors, and local- to national-scale applications with this updated land-cover data. This baseline data set is essential in determining the effects of land-cover change on climate as well as the effects of climate change on land cover.

Deforestation Dynamics Assessed in Brazilian Amazon.[13,14] There has been considerable international attention on the Brazilian Amazon Basin because of the alarming rate of destruction of this high-biodiversity biome and because it is a major terrestrial buffer against rising atmospheric CO_2, a primary driver of global warming. Land-cover change from pristine forests to other uses accounts for most of Brazil's carbon emissions. Investigators combined deforestation maps, field surveys, and satellite-based information

on vegetation phenology to characterize the fate of large (>25 hectare) clearings as cropland, cattle pasture, or regrowing forest in the years after initial clearing in Mato Grosso, the state with the highest deforestation rate and soybean production since 2001. Cropland deforestation averaged twice the size of pasture clearings, and more than 90% of the conversion to cropland occurred the first year after deforestation. Economics appears to be a major driver of this change as the area deforested for cropland per year was directly related to the mean annual soybean price. Large-scale logging is relatively new in this region, and impacts of selective logging alone have been estimated to increase the annual carbon release from deforestation in the Amazon by 4 to 7%, thus adding to the CO_2 concentration of the atmosphere. Remote-sensing techniques were applied to identify and map areas of selective logging in the tropical upland or terra firme forests of the Brazilian Amazon in 1992, 1996, and 1999. The research results indicate that selective logging is rapidly increasing in both intensity and area. By 1992, at least 6,000 km^2 of forest had been logged, and the area affected expanded by an additional 10,000 km^2 from 1992 to 1996 and 26,000 km^2 from 1996 to 1999. Selective logging within protected areas increased more than two-fold between 1992 and 1996, and more than five-fold between 1996 and 1999 in that region (see Figure 7).

Highlights of Plans for FY 2008

Urgent land-use and land-cover change priority research questions include understanding historic, current, and potential future land-use and land-cover change patterns, dynamics, and drivers; understanding the mutual effects and feedbacks between climate variability and land use/land cover; and forecasting environmental, social, economic, and human health consequences. All of these land-use and land-cover change priority issues directly influence climate by affecting atmospheric trace gas composition and surface reflectance, and are thus critical to other CCSP research elements. While both *in situ* and satellite observations are essential, two satellite sensors are especially critical: MODIS (including its next generation moderate-resolution successor the Visible/Infrared Imager/Radiometer Suite) and Landsat. Without these satellite observations, the current pace of discovery and innovation in global land-use and land-cover change climate research would not be possible. Thus, an overall priority for this research element is to ensure continuity and improvements in land-use and land-cover observations, to compare and validate the different types of observations, and to coordinate activities for analysis and synthesis of their implications and projections, as follows:

- Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
- Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

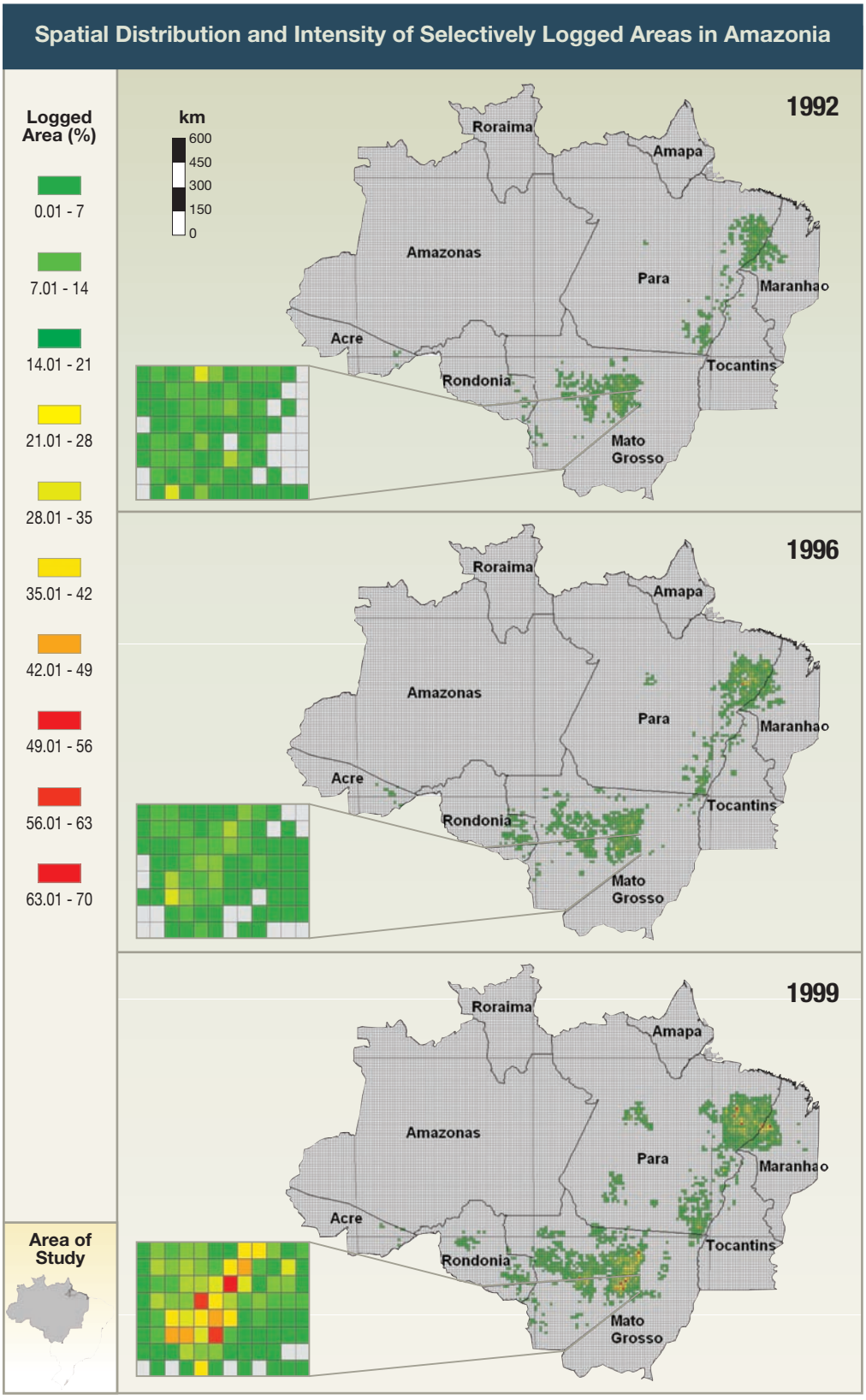


Figure 7: Spatial Distribution and Intensity of Selectively Logged Areas in the Amazon Basin. Spatial distribution and intensity of selectively logged areas summarized into 25 by 25 km grid cells in 1992, 1996, and 1999 for the Amazon Basin of Brazil. *Credit: E.A.T. Matricardi, D.L. Skole, and W.H. Chomentowski, Michigan State University; M.A. Cochrane, South Dakota State University; and M. Pedlowski, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Brazil (reproduced from the* **International Journal of Remote Sensing** *with permission from the publisher Taylor & Francis Group).*

- Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Development of Land-Use Change Models. Developing future land-use and land-cover change scenarios and understanding drivers and feedbacks are necessary to assess impacts on the environment. A tool to generate future LULCC scenarios consistent with IPCC emissions scenarios is being developed, and will be used to assess the environmental impacts of climate and land-use change regionally and nationally. This will improve projections of climate and global change and contribute to understanding of possible management risks and opportunities related to climate change. It also contributes directly to understanding the feedbacks between climate change, conservation policies, and land-use and land-cover decisions.

This activity will address CCSP Goals 3, 4, and 5 and Questions 6.1, 6.3, and 6.4 of the CCSP Strategic Plan.

Invasive Species Impacts on Land-Use and Land-Cover Change. Land use and climate change interact to influence the spread of alien or invasive species that in turn have ecological impacts that may result in climate forcings. The EPA, NASA, and USDA are coordinating solicitations to quantitatively investigate these interactions. In addition, a workshop is planned to study and determine future directions for research on interactions between land-use and land-cover change and the carbon cycle relating to climate change. These efforts help quantify climate change drivers and feedbacks, reduce uncertainties in projections of change, and improve understanding of sensitivities of natural and managed ecosystems.

This activity will address CCSP Goals 2, 3, and 4 and Questions 6.2, 6.4, and 6.5 of the CCSP Strategic Plan.

Prototype Land-Cover Mapping Activities. The National Land Cover Database effort in Alaska, Hawaii, and Puerto Rico will be finished by December 2007, marking completion of the first compilation of nationwide land cover ever produced at 30-m resolution. This will improve knowledge of Earth's present environment and its variability and form the baseline for quantifying change at high spatial resolution.

This activity will address CCSP Goal 1 and Question 6.1 of the CCSP Strategic Plan.

Landsat Data Continuity Mission. The importance of Landsat data continuity was a priority for FY 2007 and was emphasized in the FY 2007 edition of *Our Changing Planet*. Landsat Data Continuity Mission planning continues toward a proposed 2010 launch. In October 2006, NASA and USGS announced the selection and research objectives for the Landsat Science Team. The Science Team will recommend strategies for the effective use of archived data from Landsat sensors and investigate the

requirements for future sensors to meet the needs of Landsat users, including the needs of policymakers at all levels of government. The team will cooperate with other Earth-observing missions, both nationally and internationally. This will improve quantification of drivers and atmospheric forcings of climate change, contribute to improved projections of this change, and provide improved understanding of the present environment, its variability, and how it is changing.

This activity will address CCSP Goals 1, 2, and 3 and Question 6.1 of the CCSP Strategic Plan.

GLOBAL WATER CYCLE CHAPTER REFERENCES

1) **USAID**, 2007: *The Congo Basin Forests: State of the Forests 2006*. Central African Regional Program on the Environment, U.S. AID, Washington, D.C., USA, 256 pp.
2) See <eros.usgs.gov/LT/LCCEUS.html>.
3) **Acevedo**, W., J.L. Taylor, D.J. Hester, C.S. Mladinich, and S. Glavac (eds.), 2006: *Rates, Trends, Causes, and Consequences of Urban Land-Use Change in the United States*. USGS Professional Paper 1726, US Geological Survey, 200 pp. Available at <pubs.usgs.gov/pp/pp1726/pp1726.pdf>.
4) **Tobias**, K., V.C. Radeloff, K. Perzanowski, P. Hostert, and K. Perzanowski, 2006: Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing of Environment*, **103(4)**, 449-464.
5) **Lunetta**, R.S., J.F. Knight, J. Ediriwickrem, J.G. Lyon, and L.D. Worthy, 2006: Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment*, **105(2)**, 142-154.
6) **Doraiswamy**, P.C., B. Akhmedov, L. Beard, A. Stern, and R. Mueller, 2007: Operational prediction of crop yields using MODIS data and products. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences Special Publications* (in press). Available at <www.ars.usda.gov/SP2UserFiles/person/1430/ISPRS_AGRIFISH_Final.pdf>.
7) **Daughtry**, C.S.T., P.C. Doraiswamy, E.R. Hunt, A.J. Stern, J.E. McMurtrey, and J.H. Prueger, 2006: Remote sensing of crop residue cover and soil tillage intensity. *Soil and Tillage Research,* **91**, 101-108.
8) **Hayes**, D.J. and W.B. Cohen, 2007: Spatial, spectral, and temporal patterns of tropical forest cover change as observed with multiple scales of optical satellite data. *Remote Sensing of Environment,* **106(1)**, 1-16.
9) **Kueppers**, L.M., M.A. Snyder, and L.C. Sloan, 2007: Irrigation cooling effect. *Geophysical Research Letters,* **34(3)**, L03703, doi:10.1029/2006GL028679.
10) **Westerling**, A.L, H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and earlier spring increases western U.S. forest wildfire activity. *Science,* **313**, 940-943.
11) **Dore**, S., M.C. Montes-Helu, B. Sullivan, J.P. Kaye, S.C. Hart, G. Koch, and B. Hungate, 2007: The effect of intense wildfires on ecosystem gas exchange of ponderosa pine forests in northern Arizona. *North American Carbon Program Investigators meeting, 22-26 January 2007, Colorado Springs, Colorado*. Abstract E.2 p. 45. Available at <www.nacarbon.org/cgi-nacp/2007_meetings/mtg2007_agenda.pl?meeting_id=1>.
12) See <epa.gov/mrlc/nlcd.html>.
13) **Morton**, D.C., R.S. DeFries, Y.E. Shimabukuro, L.O. Anderson, E. Arai, F. del Bon Espirito-Santo, R. Freitas, and J. Morisette, 2006: Cropland expansion changes deforestation dynamics in Southern Brazilian Amazon. *Proceedings of the National Academy of Sciences,* **103(39)**, 14637-14641.
14) **Matricardi**, E.A.T., D.L. Skole, M.A. Cochrane, M. Pedlowski, and W.H. Chomentowski, 2007: Multi-temporal assessment of selective logging in the Brazilian Amazon using Landsat data. *International Journal of Remote Sensing*, **28**(1-2), 63-82.

5 Global Carbon Cycle

Strategic Research Questions

7.1 What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.2 What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.3 What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?

7.4 How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

7.5 What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?

7.6 How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

See Chapter 7 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The U.S. Carbon Cycle Science Program is clarifying the changes, magnitudes, and distributions of carbon sources and sinks; the fluxes between the major terrestrial, oceanic, and atmospheric carbon reservoirs; and the underlying mechanisms involved including human activities, fossil-fuel emissions, land use, and climate. Program scientists are now beginning to reveal and quantify some of the intricate complexities

THE NORTH AMERICAN CARBON PROGRAM

The North American Carbon Program (NACP) is designed to address Strategic Research Question 7.1 in Chapter 7 of the *CCSP Strategic Plan*. It will quantify the magnitudes and distributions of terrestrial, freshwater, oceanic, and atmospheric carbon sources and sinks for North America and adjacent oceans; enhance understanding of the processes controlling source and sink dynamics; and produce consistent analyses of North America's carbon budget that explain regional and continental contributions and year-to-year variability. This program is committed to reducing uncertainties related to the increase of carbon dioxide and methane in the atmosphere and the amount of carbon—including the fraction of fossil-fuel carbon—being taken up by North America's ecosystems and adjacent oceans.

of and interactions between the Earth's carbon reservoirs and climate.

The Carbon Cycle Science Program engages many science disciplines and extends over a broad range of spatial and temporal scales. Many Federal agencies coordinate and support the activities included under the North American Carbon Program (NACP) and the Ocean Carbon and Climate Change (OCCC) program. In FY 2008, the integration of the terrestrial, oceanic, and atmospheric investigations will be critical and will continue as a priority of the U.S. Carbon Cycle Science Program. Assimilation of carbon data into models is developing at scales from regional to global as an important means of incorporating observations into carbon cycle analyses. The goal is to develop increasingly realistic, fully coupled carbon cycle-climate models to provide insight into potential feedbacks between and drivers of these major Earth systems.

A major accomplishment for this research element involves publication of *The First State of the Carbon Cycle Report on the North American Carbon Budget and Implications for the Global Carbon Cycle* (CCSP Synthesis and Assessment Product 2.2). It synthesizes current knowledge and uncertainties about carbon in North America relevant to the United States and the rest of the world, and provides baseline information to support decisionmaking on key issues related to U.S. carbon management and policy. In FY 2008, the NACP will address key gaps and uncertainties identified in the synthesis. Other planned activities will focus on integrating carbon cycle research,

THE OCEAN CARBON AND CLIMATE CHANGE PROGRAM

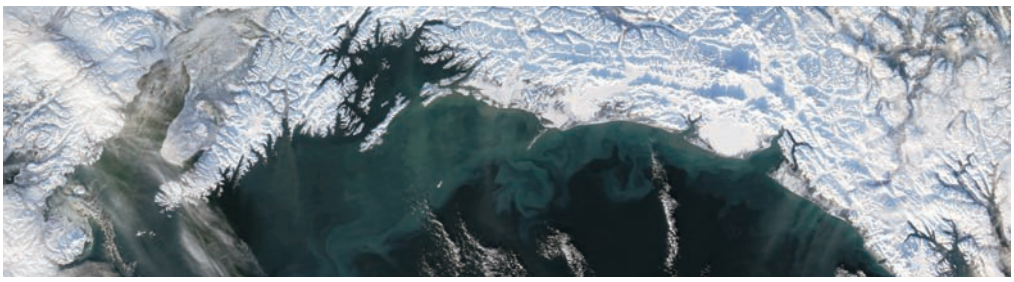
The Ocean Carbon and Climate Change (OCCC) program is designed to address Strategic Research Question 7.2 in Chapter 7 of the *CCSP Strategic Plan*. It will focus on oceanic monitoring and research aimed at determining how much atmospheric carbon dioxide is being taken up by the ocean at the present time and how climate change will affect the future behavior of the oceanic carbon sink. The terrestrial and ocean carbon programs are synergistic, integrating program activities in addressing carbon dynamics on the coastal shelves adjacent to North America, where carbon changes in the terrestrial system greatly influence carbon processes in the coastal ocean.

U.S. CARBON CYCLE SCIENCE PROGRAM

The U.S. Carbon Cycle Science Program contributes to all CCSP goals, focusing particularly on Goal 2: *Improved quantification of the forces bringing about changes in the Earth's climate and related systems*. It addresses directly the six carbon cycle questions of Chapter 7 of the *CCSP Strategic Plan*. The research element is synergistic with the Ecosystems, Global Water Cycle, Climate Variability and Change, Atmospheric Composition, Land-Use/Land-Cover Change, and Human Contributions and Responses research elements. The agencies responsible for carbon cycle research are DOE, NASA, NOAA, NSF, USDA, and USGS. Together, they have planned and are coordinating a multidisciplinary research strategy to integrate the broad range of needed infrastructure and resources, scientific expertise, and stakeholder input essential for program success and improved decision processes.

increasing observational and network capabilities, measuring carbon fluxes and stocks, conducting manipulative experiments, modeling the carbon cycle for predictive analyses, and coupling carbon models with other Earth component models for Earth system analyses. Successful completion will provide, and be measured by, integrated and accessible observational databases, quantified carbon budgets, more precise estimates of changes occurring or likely to occur, and more accurate carbon sink and source estimates.

Looking beyond FY 2008, the research element will extend its observation and network systems to high latitudes and other undersampled regions of the world. The anticipated emphasis on high-latitude research will provide critical scientific information on the carbon dynamics of the undersampled regions of North America and adjacent oceans, Antarctica, and the Southern Ocean as high-latitude warming changes system dynamics. Collaborations with Canada and Mexico under the Joint NACP (Canada, Mexico, and the United States) cooperative will be well underway. Efforts are also underway to initiate stronger international collaborations with the European Union and its research program under the CarboEurope and CarboOcean Programs. Other international initiatives and collaborations are also expected to address regional to global issues, interactions between carbon cycle dynamics and global climate change, linkages between and feedbacks within Earth systems, and the uncertainties associated with continental and oceanic carbon sources and sinks.



Highlights of Recent Research

The research highlights that follow are derived from carbon cycle science programs spanning terrestrial, oceanic, and atmospheric reservoirs and the complex interactions that link these reservoirs within the global carbon cycle.

Climate Forcing

Atmospheric carbon dioxide (CO_2) and methane (CH_4) are significant forcing agents of Earth's climate and have been increasing over the past 2 centuries as a result of human activities. Approximately 85 to 90% of today's anthropogenic emissions are attributed to fossil-fuel combustion with land-use change accounting for most of the rest. Future concentrations of carbon dioxide and methane in the atmosphere will depend on the long-term trends and variability in natural and anthropogenic emissions and the capacity of natural and managed sinks in the carbon cycle.

Distinguishing Fossil Fuel Emissions from Biological CO_2 Cycling.[1] Measurements of atmospheric $^{14}CO_2$, carbon monoxide (CO), and sulfur hexafluoride (SF_6) as tracers of fossil-fuel CO_2 emissions show that $^{14}CO_2$ provides accurate quantification of fossil-fuel CO_2. Issues remain concerning the distributions of SF_6 and CO emissions relative to CO_2 that may bias regional estimates. This research focused mainly on winter and spring data from two different regions, Colorado and New England, to test the approach under widely different conditions. The effort as a whole, however, extends to much of the atmospheric research network and is anticipated to be enhanced to produce viable regional estimates of fossil-fuel contributions to atmospheric CO_2 and CH_4 concentrations, thus allowing more accurate estimates of biological contributions to the atmospheric carbon budget.

Forest Fire Impacts on Climate Change.[2] Contemporary wisdom supports the concept that increases in temperature would lengthen the growing season in boreal ecosystems and increase the probability of fire, leading to a positive feedback between warming, fires, carbon loss, and future climate change. However, a new multi-factor analysis of the long-term effects of a well-characterized boreal forest fire indicates that the net radiative forcing may be negative. During the first year after the fire, all factors combined to increase radiative forcing ($34 \pm 31\ Wm^{-2}$ of burned area), but when averaged over an 80-year fire cycle the net effect was to decrease radiative forcing ($-2.3 \pm 2.2\ Wm^{-2}$). The reason is that multidecadal increases in surface reflectance had a larger impact than the fire-emitted greenhouse gases. This study illustrates the importance of interdisciplinary, multi-factor analysis and the need to examine effects

over decades to centuries in order to fully understand the impacts of disturbance and the feedbacks between Earth's physical and biogeochemical systems.

Changes in Forest and Soil Carbon.[3,4] A 13-year study of carbon flux measurements at the Harvard Forest clearly shows that the uptake of atmospheric CO_2 has been increasing in this ecosystem; mean carbon gain for the 1992 to 2004 period was 2.4 metric tons of carbon ha^{-1} yr^{-1}, and carbon uptake has been increasing at the rate of 0.15 metric ton of carbon ha^{-1} yr^{-1}. This magnitude of forest carbon gain is typical of other findings from the AmeriFlux observation network. In the top 20-cm soil layer in preserved old-growth forests in southern China, a study shows that soils accumulated atmospheric carbon at an unexpectedly high rate from 1979 to 2003. These long-term observations show that the rate of photosynthetic carbon assimilation can exceed ecosystem carbon loss by respiration. Such studies demonstrate the significant potential for terrestrial sources and sinks to affect atmospheric CO_2 increases.

Terrestrial Carbon Cycle

The terrestrial carbon cycle is composed of a complex set of interactive biological, chemical, and physical processes that transfer carbon between land, oceans, and the atmosphere. Collectively, these processes influence atmospheric CO_2 and CH_4 concentrations. Improving the scientific understanding of the role of these reservoirs and links in the carbon cycle reduces the uncertainty about the factors influencing greenhouse gas increases and provides a stronger basis for climate change decision support, in particular for carbon management to mitigate CO_2 and CH_4 increases.

Carbon Storage in Forested Ecosystems.[5,6,7] Forested ecosystems in the United States have a major impact on regional and global sources of CO_2—taking up 25 to 50% of CO_2 emitted annually from fossil-fuel combustion in the United States, a significant amount since the United States accounts for about 20% of global emissions. The CO_2 Boundary-Layer and Regional Airborne (COBRA) study developed model-data fusion methods to determine accurate regional- and continental-scale carbon budgets and to attribute carbon fluxes to

specific causes and processes. Model predictions for the 1990s, with and without contributions from CO_2 fertilization, are within the range of uncertainties; but, in the absence of CO_2 fertilization, the carbon sink in forests will approach zero by 2050, as the effects of forest harvesting offset those of agricultural land abandonment. Long-term measurements, such as those undertaken by AmeriFlux and tall-tower networks, are critical for detecting the signatures of processes that give rise to long-term uptake of atmospheric CO_2 by major ecosystems of North America.

Seasonality of Amazonian Forests.[8] Measurements of vegetation "greenness" from the Moderate Resolution Imaging Spectrometer (MODIS) on the Terra and Aqua satellites revealed an increase in greenness across Amazonian forests during the dry season, a pattern opposite to what had been previously thought and portrayed in models (see Figure 8). Researchers explained that the deep-rooted forests are able to access deep soil water and take advantage of the increased sunlight in the dry season. In contrast, areas converted to pastures, with more shallowly rooted plants, show the expected decline in greenness during the dry season. With this knowledge, scientists can refine models used to represent the tropical biosphere and how it exchanges carbon with the atmosphere, thus improving long-term carbon cycle and climate models.

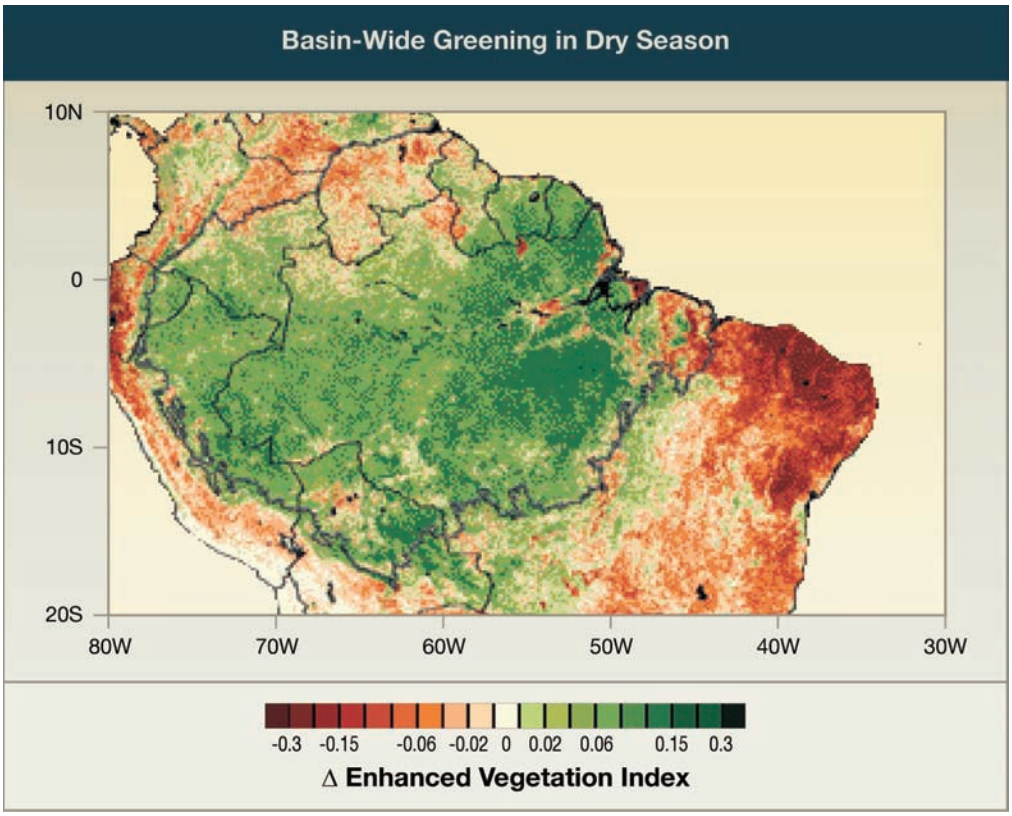
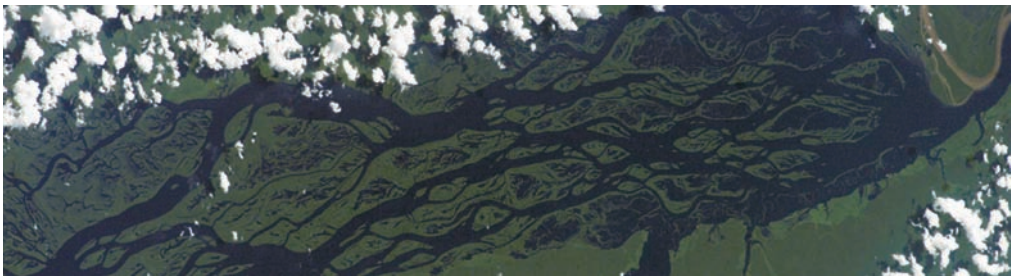
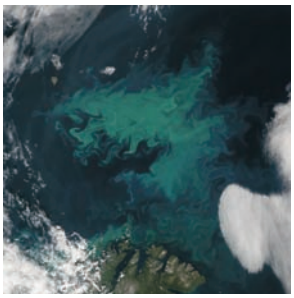


Figure 8: Basin-Wide Greening in Dry Season. Amazon rainforest basin-wide image of average (2000-2005) Enhanced Vegetation Index (EVI) change between the wet (October) and dry (June) seasons. Green colors depict "greening" and red colors depict "browning" in the dry season. *Credit: A.R. Huete, K. Didan, P. Ratana, and S.R. Seleska, University of Arizona; Y.E. Shimabukuro, Instituto Nacional de Pesquisas Espaciais, Brazil; L.R. Hutyra, Harvard University; W. Yang and R. Myneni, Boston University; and R.R. Nemani, NASA / Ames Research Center (reproduced from* **Geophysical Research Letters** *with permission from the American Geophysical Union).*



Carbon Storage in Forest Soils.[9] A novel approach was developed to monitor carbon sequestration in aggregates of small particles that has profound implications for carbon protection in soil. The approach is based on ultra-small angle X-ray scattering of synchrotron X-rays that indicates the tendency of soil containing organic carbon to become more stable as a greater proportion of the soil micropores become filled. This mechanism suggests that the potential for organic matter storage in soil is larger than generally thought because it is neither limited by the surface area of minerals nor dependent on strong sorption by these surfaces. Another critical implication is that agricultural management and land use, particularly as they affect the stability of a microporous soil structure, can significantly alter the extent of carbon sequestration via both positive and negative feedbacks.



Oceanic Carbon Cycle

The global ocean carbon sink is an important component of the climate system that regulates the uptake, storage, and release of CO_2 and other climate-relevant chemical species to the atmosphere. The future behavior of this carbon sink is quite uncertain because of the potential impacts of climate change on many ocean processes.

Ocean Carbon Dynamics.[10] The air-sea exchange and storage of CO_2 in the tropical and extra-tropical North Pacific Ocean play a key role in the global carbon cycle. Upwelling in the equatorial Pacific brings high carbon content water to the surface, generating the ocean's largest natural source of CO_2 to the atmosphere. The tropical Pacific outgassing is well known to respond very sensitively to climatic fluctuations, particularly the El Niño Southern Oscillation (ENSO), with outgassing nearly vanishing during a fully developed El Niño. Modeling studies have suggested that fluctuations in the tropical Pacific dominate the global air-sea CO_2 flux variability on interannual time scales. The most important results on surface ocean CO_2 partial pressure (pCO_2) and air-sea CO_2 flux variability in the North Pacific to date are summarized in Figure 9. The small plots in each of the regions illustrate the observed trends in surface ocean pCO_2 over the last 2 decades. Most regions show a steady increase at rates roughly the

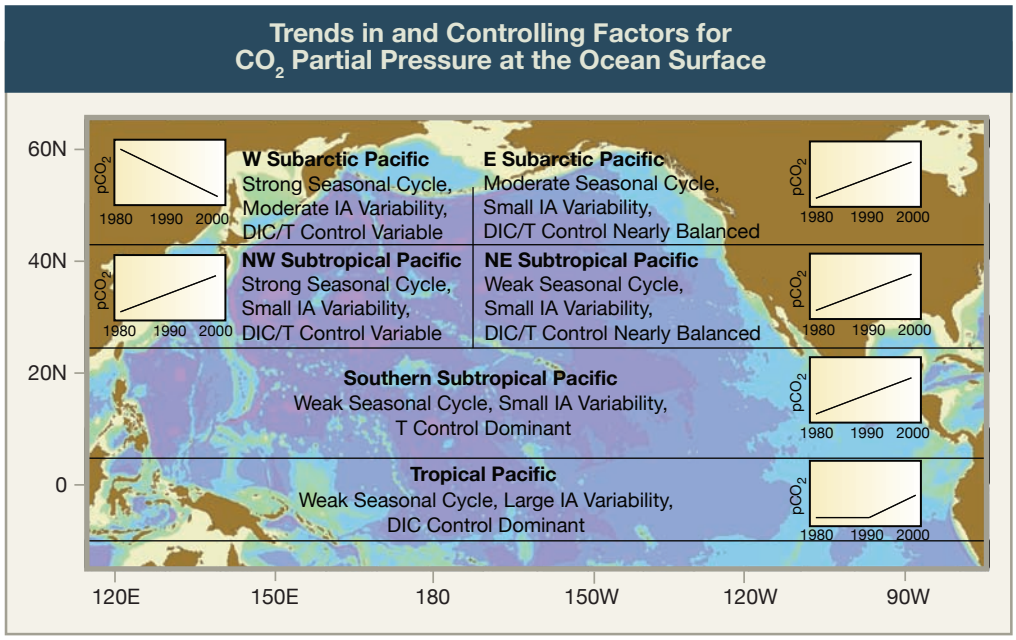


Figure 9: Trends in and Controlling Factors for CO_2 Partial Pressure at the Ocean Surface. This illustration provides a summary of trends in CO_2 partial pressure (pCO_2) at the ocean surface and controls in the North Pacific. Increasing trends in the subplots indicate that ocean CO_2 is increasing with the atmospheric concentration as expected. Flat or decreasing trends indicate that other processes are working to counteract the natural CO_2 increase. The text in the figure identifies the observed variability and primary controls on the observed trends. IA, DIC, and T stand for interannual variability, dissolved inorganic carbon, and temperature, respectively. *Credit: C. Sabine, NOAA / Pacific Marine Environmental Laboratory and N. Gruber, University of California - Los Angeles (reproduced from the* **Journal of Geophysical Research** *with permission from the American Geophysical Union).*

same as that of atmospheric pCO_2 over the same time period. The two notable exceptions are the far western subarctic region where surface water pCO_2 has decreased with time, and the equatorial Pacific which shows a rate of pCO_2 increase akin to that of atmospheric CO_2 only after 1990, while oceanic pCO_2 remained nearly constant before. The reasons behind these different trends are still under investigation, but they highlight the need for continuing observations of the oceanic carbon system.

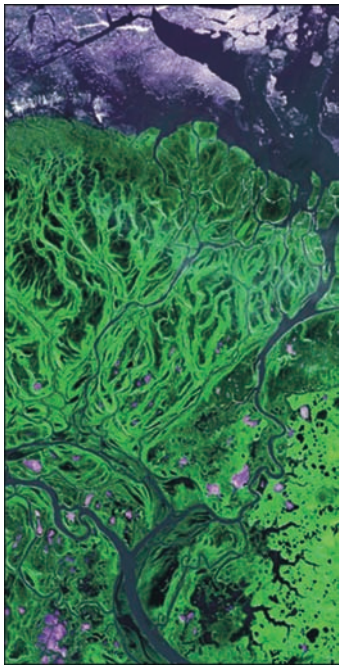
Coastal Carbon Storage.[11,12] Recent research on carbon storage in intertidal and subtidal estuarine ecosystems in the northeastern United States shows that these systems store more organic carbon to a depth of 1 m than forest soils in the adjacent uplands. The reason for this observation is that subtidal and intertidal soils are generally located on stable landforms and are accumulating organic carbon annually as sea level rises. Contrary to the common assumption that the carbon being stored in these ecosystems is from terrestrial vegetation, the majority of the organic carbon found was fixed by benthic algae. These results indicate the importance of including subtidal and intertidal estuarine ecosystems in global carbon models.

High-Latitude Systems

High-latitude systems are becoming increasingly important sources of CO_2 and CH_4 in the atmosphere as regional warming changes carbon dynamics in the cold regions. Understanding carbon dynamics in high-latitude systems and the factors that may lead to changes in those dynamics are crucial elements of global carbon modeling and essential for understanding the linkages and feedbacks between carbon, ecosystems and land cover, hydrology, and climate variability and change.

Arctic Ocean Sensitivity to Climate Change.[13] The Arctic Ocean and adjacent continental shelf seas are particularly sensitive to long-term changes and low-frequency modes of atmosphere-ocean-sea ice forcing arising from climate change. The cold, low-salinity surface waters of the Canadian Basin of the Arctic Ocean are undersaturated with respect to CO_2 in the atmosphere and thus the region has the potential to take up atmospheric CO_2, although presently covered over by sea ice. Undersaturated CO_2 conditions in the Arctic Ocean are maintained by export of water with low dissolved inorganic carbon content and modified by intense seasonal shelf primary production. Sea ice extent and volume in the Arctic Ocean have decreased over the last few decades, and researchers have estimated that the Arctic Ocean sink for CO_2 has nearly tripled over the last three decades (24 to 66 million metric tons of carbon per year) due to sea ice retreat with future sea ice melting projected to enhance air-to-sea CO_2 flux by about 28% per decade.

Carbon Export from Permafrost Ecosystems.[14,15] The Yukon River discharges almost 7.8 million metric tons of carbon to the Bering Sea annually, of which about 30% is organic. With permafrost thawing throughout the Yukon basin, scientists are concerned about a potentially large release of bio-available dissolved and particulate organic carbon to the Arctic Ocean. Radiocarbon analysis of the discharged carbon indicates that most of the dissolved organic carbon is modern, but that particulate carbon has a large component that is thousands of years old. This is consistent with most particulate organic carbon originating from erosion of riverbanks and most dissolved organic carbon originating from surface runoff—not from thawed permafrost. Earlier work suggests that this pattern may continue if newly thawed dissolved organic carbon is respired rather than exported downstream.



Methane Release from Thawed Permafrost Lowlands.[16] Global warming is causing permafrost to thaw in areas of Alaska, Canada, and Siberia. When permafrost thaws, localized areas in a landscape may collapse and flood, forming wetlands where there were once forests. According to recent research, these wetlands release large amounts of CH_4 to the atmosphere compared to the surrounding forests. Wetlands in interior Alaska formed from permafrost thaw released up to 35 times more CH_4 per unit area than the surrounding forest soils over 1 year. If widespread wetland formation occurs across areas of thawing permafrost, the increase in CH_4 release could have significant impacts on global climate change because it is a strong greenhouse gas.

Fire Disturbance and Permafrost Degradation in Boreal Regions.[17,18] Fire regimes and permafrost degradation, which are closely linked through organic soil (ground fuel) in boreal regions, have the potential to shift in response to changes in climate. Over the past few decades, fire disturbance maintained the heterogeneous patterns of both permafrost and vegetation in boreal forests, mainly through the regulation of soil temperature by organic soil thickness. More severe burns such as occurred in 2004 and 2005, however, may promote a vastly different landscape depending in part on how much post-fire organic soil is retained. In all boreal landscapes, whether burned or not, ecosystem response to climate as well as associated carbon and energy exchanges depend largely on whether thaw-water is pooled on or drained from the landscape. Over the next several years, investigations will focus on detecting and studying the fate of both surface water and ecosystem carbon under various thaw regimes in the Alaskan interior.

Carbon Management and Decision Support

Carbon cycle research provides scientific input to policy and resource management decisions for carbon management and mitigation of climate change. The results of research supported by the carbon cycle research element of the CCSP are informing carbon management, as described in the research highlights below, and their impact is expected to increase over the course of this program.

The First State of the Carbon Cycle Report: CCSP Synthesis and Assessment Product 2.2.[19] This report finds that in 2003, North American terrestrial carbon sinks removed approximately 520 million metric tons of carbon per year (±50% with 95% confidence) from the atmosphere, which is equivalent to approximately 30% of North American fossil-fuel emissions in 2003. Approximately 50% of the sink is due to the regrowth of forests in the United States on former agricultural land and on forested land recovering from harvest. This sink is expected to decline. As forests mature they grow more

slowly and take up less carbon from the atmosphere. The current source to sink imbalance of more than 3 to 1 (ratio of fossil-fuel emissions to net terrestrial carbon uptake) and the potential trend of increasing sources and decreasing sinks suggest that addressing imbalances in the North American carbon budget will likely require actions focused on reducing fossil-fuel emissions. Options focused on enhancing carbon sinks in soils and vegetation can contribute as well, but their potential is far from sufficient to offset current fossil-fuel emissions.

Carbon Sequestration in Low-Production Lands.[20] Sequestering carbon through afforestation on low-production cropland and rangeland may be a means of reducing net carbon emissions from the United States and a process worth monitoring for carbon management. Information on the potential for such sequestration was derived through application of an ecosystem carbon model using a "greenness" product obtained from the Advanced Very High-Resolution Radiometer (AVHRR)—a space-borne instrument. The model results, at 8-km resolution, show the spatial variability in monthly net primary production (NPP) and accumulation rates of biomass (i.e., carbon storage) in low-production cropland and rangelands (see Figure 10). The model predictions indicate potential carbon sequestration rates of 300 million metric tons per year—the equivalent of 20% of the current U.S. carbon emissions from fossil-fuel combustion.

Forest Management.[21] Healthy, productive forests constitute an important terrestrial buffer against rising atmospheric CO_2, a major driver of climate change. A team of American and Brazilian scientists, using extensive high-resolution multi-satellite analyses, concluded that forest harvests in the Brazilian Amazon are dominated by practices that leave forests more susceptible to drought and fire and threaten their long-term health and productivity. At the same time, they found that recently logged forests have a high probability of being cleared for farming and settlements, further reducing the potential of this land for carbon storage. Recently, the Brazilian Government enacted legislation to regulate forest lands and the timber industry, and this new policy has the potential to maintain forests under long-term timber management.

Landowners' Greenhouse Gas Reporting Tools.[22,23,24] A new set of tools have been developed for the agricultural and forestry sectors to enable farmers and landowners to estimate carbon sequestration and greenhouse gas emissions. These sectors can reduce atmospheric concentrations of greenhouse gases by increasing carbon sequestration in biomass and soils, by reducing fossil-fuel emissions through use of climate-neutral fuels, and by substituting agricultural and forestry products that

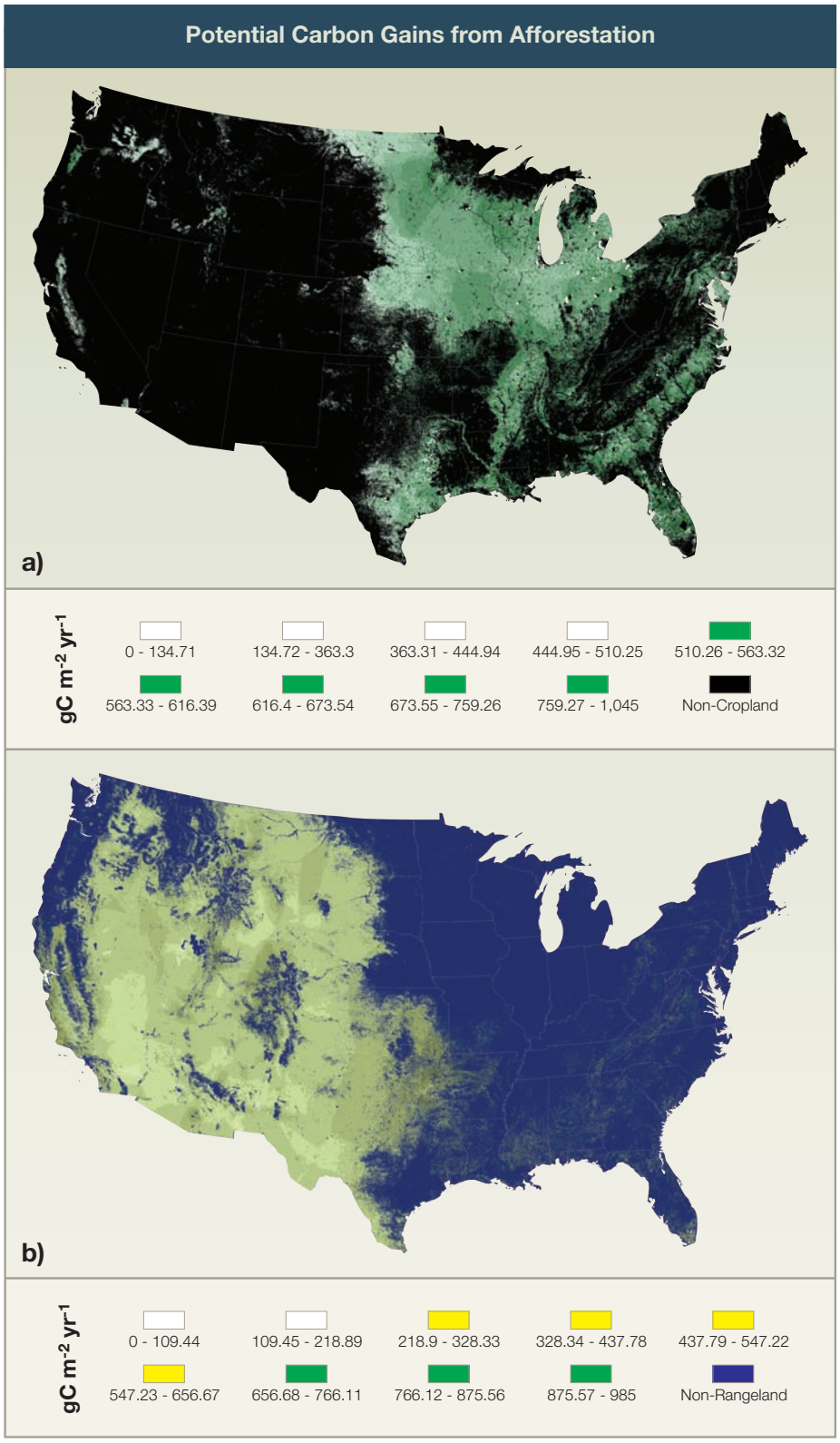


Figure 10: Potential Carbon Gains from Afforestation. Potential afforestation carbon gains in (a) relatively low-production crop areas, and (b) relatively low-production rangelands. Both panels are mapped to show predicted gross carbon sink flux per year at 1-km resolution. Corrections for probable net primary productivity loss over time due to decomposition, disturbance, and aging in predicted forest stands are not included. *Credit: C. Potter and M. Fladeland, NASA / Ames Research Center; S. Klooster and V. Genovese, California State University – Monterey Bay; and S. Hiatt, San Jose State University and Education Associates (reproduced from* **Climatic Change** *with permission from Springer Netherlands).*

require less energy than other materials to produce. The tools have been adopted by DOE for use in the National Voluntary Greenhouse Gas Reporting Registry. The tools could also be adopted for use in state or regional registries and for use by voluntary greenhouse gas markets, opening new opportunities to reward landowners for reducing atmospheric greenhouse gases, enabling industry to meet global environmental goals at lower costs, and strengthening rural economies while protecting the environment.

Societally Useful Measure of Greenhouse Gas Forcing.[25] The challenge of effectively informing society led scientists to develop a simple way to express greenhouse gas forcing for decisionmakers and the public. The perturbation to radiative climate forcing that has the largest magnitude and smallest scientific uncertainty is the forcing related to changes in long-lived and well-mixed greenhouse gases—in particular CO_2, CH_4, nitrous oxide (N_2O) and halocarbons. The change in annual total radiative forcing by these gases since the pre-industrial era (1750) is used to define the Annual Greenhouse Gas Index (AGGI), which is normalized to radiative forcing in 1990. The AGGI shows that between 1990 and 2006 there was a 23% increase in radiative forcing due to long-lived greenhouse gases. This index is designed to help bridge the technical gap between scientists and decisionmakers and is now used and disseminated by the World Meteorological Organization.

Highlights of Plans for FY 2008

Continuing integration within the NACP and the OCCC program will provide better estimates of the North American carbon budget including the roles of adjacent ocean basins. More comprehensive global and regional models and analyses, driven by improved *in situ* measurements and experiments, reservoir inventories, and remote sensing will provide better forecasts and understanding of critical carbon cycle dynamics.

Advanced Carbon Models. Research will continue to develop carbon cycle and coupled carbon-climate models that are more comprehensive in their treatment of significant carbon dynamics and drivers, including those involving or stemming from human activities. These advanced models will incorporate multiple, interacting factors, address time scales of decades to centuries, and integrate across spatial scales. Carbon data assimilation at both regional and continental scales will continue to integrate multiple data streams including fluxes by eddy-covariance methods, atmospheric CO_2 and CH_4 concentrations using tower-based instruments, and aircraft and satellite remote-sensing observations. An important aspect of these integrated investigations is the potential to reveal expected drivers within the carbon cycle and climate system,

and especially in those systems where sensitivities of carbon processes and stocks to climate change are high (e.g., Arctic and boreal systems). Modeling research focusing on the Southern Ocean and Antarctica will capitalize on existing and impending remote and *in situ* observations and will include synthesized data sets, existing models, and data assimilation techniques to advance the ability to quantify southern high-latitude sensitivities and variability. Significant advances are expected in regional and global carbon cycle modeling.

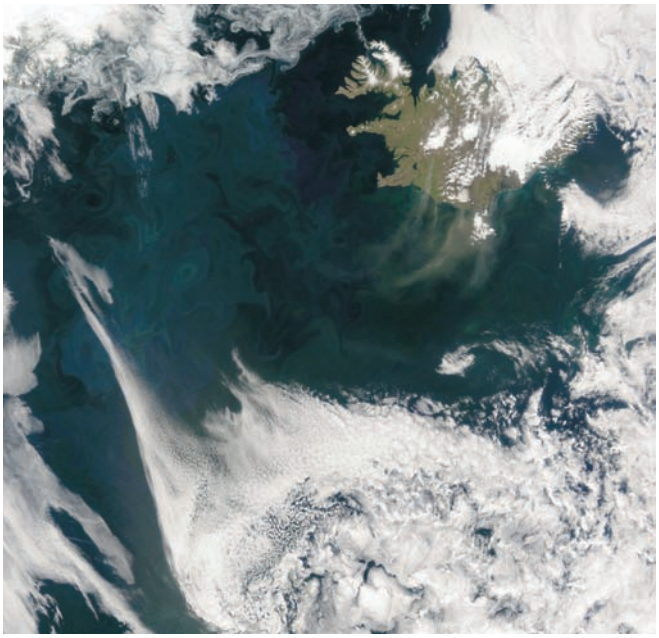
These activities will address Goals 2, 3, and 5 and Questions 7.1, 7.2, 7.4, and 7.5 of the CCSP Strategic Plan.

Atmospheric Monitoring. Measurements of radiative trace species (including CO_2 and CH_4), started six years ago at Summit, Greenland, will continue, and measurements will be expanded to include tracers of carbon sources (e.g., hydrofluorocarbons) with new instrumentation. Weekly carbon cycle flask measurements will continue across Arctic areas in Canada, Norway, Iceland, Finland, the North Atlantic, and Alaska. A collaborative effort of U.S. agencies in the Yukon will install instrumentation for continuous, vertical sampling within a 300-m boundary layer. Aircraft sampling for carbon cycle gases will be expanded to sites in Saskatchewan, Canada and Poker Flats, Alaska. If funding permits, aircraft sampling will be added over Churchill on Hudson Bay, Manitoba, and several other sites. International cooperation continues with Russia at the Baseline Observatory on the central Siberian Arctic Ocean coast where carbon gas measurements will be conducted, particularly the measurements of CH_4 that

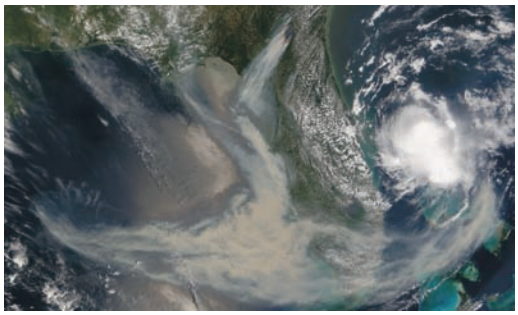
could be released from wetlands as the northern high latitudes continue to warm. In the Antarctic, flask gas sampling will continue at the South Pole Station, and at Halley, Syowa, and Palmer on the Antarctic coast. Carbon flask sampling will continue across the Drake Passage and around Antarctica on the support ship from Ushuaia to Palmer and the annual Chinese cruise, respectively.

These activities will address Goals 2, 3, and 4 and Questions 7.1, 7.2, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

Global Ocean Carbon. Ongoing and new studies will continue to address understanding of the ocean carbon cycle and its effects on ocean carbon dynamics. Of particular interest are the feedbacks and drivers of ocean chemistry and biology, the biotic and abiotic partitioning of carbon, and constraints on ocean carbon sequestration. An interagency field study of air-sea CO_2 flux and remotely sensed data in the high-latitude Southern Ocean during the 2007-2008 austral summer will focus on understanding both (a) the kinetics of gas exchange and the factors controlling it, and (b) the physical and biogeochemical factors controlling the exchange of CO_2 across the air-sea interface, in the context of developing parameterizations for those factors that can ultimately be remotely sensed to determine regional and global air-sea CO_2 fluxes. The Southern Ocean Gas Exchange Experiment (SO GasEx) will be conducted in the Atlantic sector of the Southern Ocean. Shipboard studies will include physical, chemical, biological, and meteorological measurements.



These activities will address Goals 2 and 3 and Questions 7.2, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

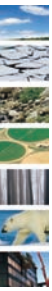


Satellite Remote Sensing. A new satellite will be launched with the Orbiting Carbon Observatory (OCO) to provide, for the first time, consistent atmospheric carbon observations globally from space. Measurements made from the observatory will permit carbon data assimilation systems to derive estimates of carbon sources and sinks with far higher spatial and temporal resolutions.

This activity will address Goals 2 and 3 and Questions 7.1, 7.2, 7.4, and 7.5 of the CCSP Strategic Plan.

Carbon Management and Decision Support. New projects are underway that will allow government agencies, industry associations, and private landowners to include carbon management information derived from data, ecosystem models, and on-line tools (products of carbon cycle science research) into near- and long-term resource management decisions and policies. These projects are having a particular impact on forest management and agricultural practices. Projects will continue beyond the fiscal year to evaluate the utility of new observations of carbon in the atmosphere (e.g., from OCO to monitor and manage carbon sources and sinks) and to identify key carbon management questions that will benefit from a high-latitude priority planned for FY 2009.

These activities will address Goals 2 and 4 and Questions 7.3, 7.4, and 7.6 of the CCSP Strategic Plan.



GLOBAL CARBON CYCLE CHAPTER REFERENCES

1) **Turnbull**, J.C., J.B. Miller, S.J. Lehman, P.P. Tans, R.J. Sparks, and J. Southon, 2006: Comparison of $^{14}CO_2$, CO, and SF_6 as tracers for recently added fossil fuel CO_2 in the atmosphere and implications for biological CO_2 exchange. *Geophysical Research Letters*, **33**, L01817, doi:10.1029/2005GL024213.

2) **Randerson**, J.T., H. Liu, M.G. Flanner, S.D. Chambers, Y. Jin, P.G. Hess, G. Pfister, M.C. Mack, K.K. Treseder, L.R. Welp, F.S. Chapin, J.W. Harden, M.L. Goulden, E. Lyons, J.C. Neff, E.A.G. Schuur, and C.S. Zender, 2006: The impact of boreal forest fire on climate warming. *Science*, **314**, 1130-1132.

3) **Urbanski**, S., C. Barford, S. Wofsy, C. Kucharik, E. Pyle, J. Budney, K. McKain, D. Fitzjarrald, M. Czikowsky, and J.W. Munger, 2006: Factors controlling CO_2 exchange on time scales from hourly to decadal at Harvard Forest. *Journal of Geophysical Research*, **112**, G02020, doi:10.1029/2006JG000293.

4) **Zhou,** G., S. Liu, Z. Li, D. Zhang, X. Tang, C. Zhou, J. Yan, and J. Mo, 2006: Old-growth forests can accumulate carbon in soils. *Science*, **314**, 1417, doi:10.1126/science.1130168.

5) **Albani**, M., P.R. Moorcroft, G.C. Hurtt, and S.W. Pacala, 2006: The contributions of land-use change, CO_2 fertilization and climate variability to the carbon sink in the Eastern United States. *Global Change Biology*, **12**, 2370-2390.

6) **Matross**, D.M., A.E. Andrews, P. Mahadevan, C. Gerbig, J.C. Lin, S.C. Wofsy, B.C. Daube, E.W. Gottlieb, V.Y. Chow, J.T. Lee, C. Zhao, P.S. Bakwin, J.W. Munger, and D. Hollinger, 2006: Estimating regional carbon exchange in New England and Quebec by combining atmospheric, ground-based, and satellite data. *Tellus*, **58B**, 344-358.

7) **Pathmathevan** M., S.C. Wofsy, D.M. Matross, X. Xiao, J.C. Lin, C. Gerbig, J.W. Munger, V.Y. Chow, and E. Gottlieb, 2007: A satellite-based biosphere parameterization for net ecosystem CO_2 exchange: Vegetation Photosynthesis and Respiration Model (VPRM). *Global Biogeochemical Cycles* (in press).

8) **Huete**, A.R., K. Didan, Y.E. Shimabukuro, P. Ratana, S.R. Saleska, L.R. Hutyra, W. Yang, R.R. Nemani, and R. Myneni, 2006: Amazon rainforests green-up with sunlight in dry season. *Geophysical Research Letters*, **33**, L06405, doi:10.1029/2005GL025583.

9) **McCarthy**, J.F., J. Ilavsky, L.M. Mayer, J. J. Dastrow, E. Perfect, and J. Zhuang, 2007: Protection of organic carbon in soil microaggregates occurs via restructuring of aggregate porosity and filling of pores with accumulating organic matter. *Geochimica et Cosmochimica Acta* (in press).

10) **Sabine**, C.L. and N. Gruber, 2006: Introduction to special section on North Pacific Carbon Cycle Variability and Climate Change. *Journal of Geophysical Research*, 111, C07S01, doi:10.1029/2006JC003532.

11) **Jespersen**, J.L. and L.J. Osher, 2007: Carbon storage in the soils of a mesotidal Gulf of Maine estuary. *Soil Science Society of America Journal* (in press).

12) **Osher**, L.J. and C.T. Flannagan, 2007: Soil/landscape relationships in a mesotidal Maine estuary. *Soil Science Society of America Journal* (in press).

GLOBAL CARBON CYCLE
CHAPTER REFERENCES (CONTINUED)

13) **Bates**, N.R., S.B. Moran, D.A. Hansell, and J.T. Mathis, 2006: An increasing CO_2 sink in the Arctic Ocean due to sea-ice loss. *Geophysical Research Letters*, **33**, L23609, doi:10.1029/2006GL027028.

14) **Striegl**, R.G., G.R. Aiken, M.M. Dornblaser, P.A. Raymond, and K.P. Wickland, 2005: A decrease in discharge-normalized DOC export by the Yukon River during summer through autumn. *Geophysical Research Letters*, **32**, L21413, doi:10.1029/2005GL024413.

15) **Striegl**, R.G., M.M. Dornblaser, G.R. Aiken, K.P. Wickland, and P.A. Raymond, 2006: Carbon export and cycling by the Yukon, Tanana, and Porcupine Rivers, Alaska, 2001-2005. *Water Resources Research*, **43**, doi:10.1029/2006WR005201.

16) **Wickland**, K.P., R.G. Striegl, J.C. Neff, and T. Sachs, 2006: Effects of permafrost melting on CO_2 and CH_4 exchange of a poorly drained black spruce lowland. *Journal of Geophysical Research*, **111**, G02011, doi:10.1029/2005JG000099.

17) **Harden**, J.W., K.L. Manies, J.C. Neff, and M.R. Turetsky, 2006: Effects of wildfire and permafrost on soil organic matter and soil climate in interior Alaska. *Global Change Biology*, **12**, 1-13, doi:10.1111 /j.1365-2486.2006.01255.x.

18) **Carrasco**, J.J., J.C. Neff, and J.W. Harden, 2006: Modeling physical and biogeochemical controls over carbon accumulation in a boreal forest soil. *Journal of Geophysical Research*, **111**, G02004, doi:10.1029/2005JG000087.

19) **CCSP**, 2007: *The North American Carbon Budget and Implications for the Global Carbon Cycle*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Dilling, L. and A. King (eds.)]. National Oceanic and Atmospheric Administration, Boulder, CO, USA, 260 pp.

20) **Potter**, C., S. Klooster, S. Hiatt, M. Fladeland, V. Genoveses, and P. Gross, 2007: Satellite-derived estimates of potential carbon sequestration through afforestation of agricultural lands in the United States. *Climatic Change*, **80**, 323-336, doi: 10.1007/s10584-006-9109-3.

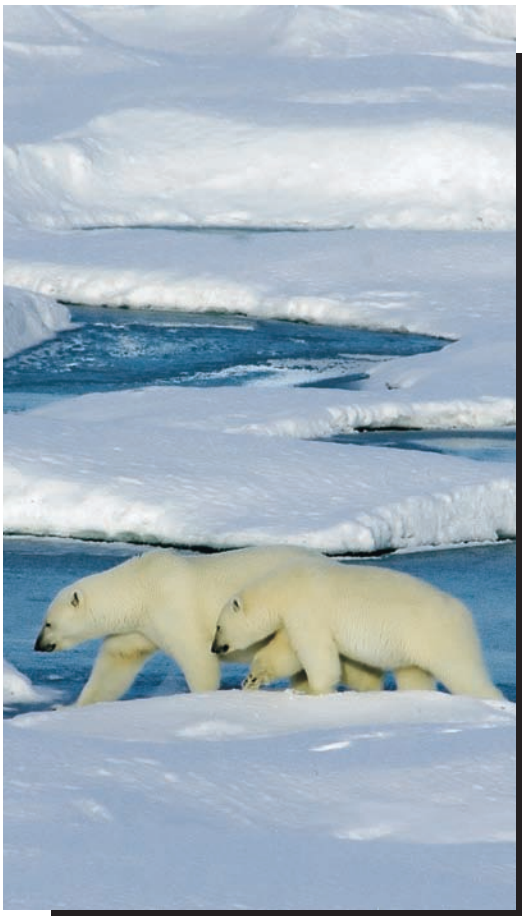
21) **Asner**, G.P., E.N. Broadbent, P.J.C. Oliveira, M. Keller, D.E. Knapp, and J.N.M. Silva, 2006: Condition and fate of logged forests in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, **103**, 12947-12950.

22) **Birdsey**, R.A, 2006: Carbon accounting rules and guidelines for the United States forest sector. *Journal of Environmental Quality*, **35**, 1518-1524.

23) **Smith**, J., E.L.S. Heath, K.E. Skog, and R.A. Birdsey, 2006: *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*. Gen. Tech. Rep. NE-343. USDA Forest Service, Northeastern Research Station, Newtown Square, PA, 216 pp.

24) Reporting guidelines are available at the Energy Information Administration web site: <eia.doe.gov/oiaf/1605/aboutcurrent.html>.

25) **Hofmann**, D.J., J.H. Butler, T.J. Conway, E.J. Dlugokencky, J.W. Elkins, K.A. Masarie, S.A. Montzka, R.C. Schnell, and P. Tans, 2006: Tracking climate forcing: The Annual Greenhouse Gas Index. *EOS, Transactions of the American Geophysical Union*, **87(46)**, 509-511.



6 Ecosystems

Strategic Research Questions

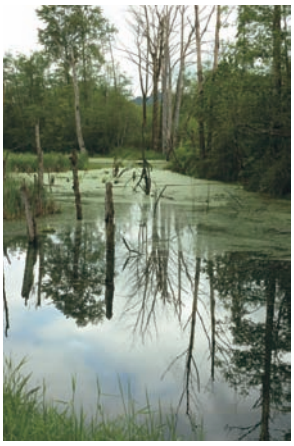
8.1 What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?

8.2 What are the potential consequences of global change for ecological systems?

8.3. What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

See Chapter 8 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The terrestrial and marine ecosystems that make up the biosphere provide critical goods and services to humanity. These include food, fiber, fuel, genetic resources, pharmaceuticals, cycling and purification of water and air, regulation of weather and climate, and natural beauty. Recent and ongoing global environmental changes—including climatic change, changes in atmospheric composition, land-use change, habitat fragmentation, pollution, and spread of invasive species—are affecting the structure and functioning of some ecosystems, and therefore the goods and services that they provide. In turn, many ecological effects of global environmental change have the potential for feedbacks (either positive or negative) to climatic and other environmental changes. Furthermore, because many global environmental changes are expected to increase in magnitude in the coming decades, the potential exists for more significant effects on ecosystems and their goods and services. Reducing scientific uncertainties about the potential effects of global change on ecosystems, as well as the feedbacks from ecosystems to global change processes, remains a CCSP priority.



In FY 2008, the CCSP Ecosystems Interagency Working Group (EIWG) will continue with its planning, implementation, and analysis of research programs to vigorously accomplish the *CCSP Strategic Plan* goals related to ecosystem research. One focus will be increased efforts to provide the scientific basis for improved ecological forecasts of the effects of climatic change on the structure and functioning of terrestrial and marine ecosystems, including the many goods and services that these ecosystems provide. The EIWG will continue its FY 2007 focus on the interplay between changing climate and the productivity and biodiversity of ecosystems, with an emphasis on improving understanding of ecological processes to accelerate model development and analysis. These activities will include the funding of two topics of particular urgency: (1) the vulnerability of coastal ecosystems, both terrestrial and aquatic, to climate-related changes, including sea-level rise, increased sedimentation and runoff, increased storm frequency or intensity, saltwater intrusion, and oceanic warming; and (2) warming-induced changes in high-latitude and high-elevation ecosystems, including changes in species composition, alterations in the timing of water availability, and migration of the tree line. These topics require additional research on underlying ecological processes and responses and the development of models linking geophysical and ecological phenomena. Strategies for implementation include new *in situ* experimental research projects; observations of ecosystems at local, regional, and global scales; synthesis and analysis of diverse ecological data sets, including those from manipulative experiments; and ecological model development and evaluation.

Efforts of the EIWG contribute to all five CCSP goals, with an emphasis on Goal 4 (to "understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes"). EIWG activities directly address questions 8.1, 8.2, and 8.3 from the *CCSP Strategic Plan*. Synergies and interactions exist with other CCSP research elements, including, but not limited to, the Climate Variability and Change, Global Water Cycle, Global Carbon Cycle, and Land-Use/Land-Cover Change research elements.

The agencies participating in the EIWG work collaboratively to plan and execute research described in the *CCSP Strategic Plan*. Many of the research accomplishments and plans described in this chapter are the outcome of joint efforts among multiple agencies. A number of these activities also involve collaborations between the agencies and non-Federal partners and cooperators. The EIWG actively engages the larger scientific research community to obtain input to, and feedback on, its evolving research plans.

Highlights of Recent Research

The following are selected highlights of recent ecosystems research supported by CCSP-participating agencies.

Quantifying Potential Ecosystem Feedbacks to Climatic Change.[1] Historical evidence shows that atmospheric greenhouse gas concentrations increase during periods of warming, implying a positive feedback from ecosystems to future climatic change. The feedbacks for carbon dioxide (CO_2) and methane (CH_4) were quantified by combining the mathematics of feedback with empirical ice core information and general circulation model (GCM) climatic sensitivity. It was found that the warming of 1.5 to 4.5°C associated with anthropogenic doubling of CO_2 in GCMs is amplified to 1.6 to 6.0°C warming. Indeed, there is growing experimental evidence that terrestrial ecosystems will amplify warming in the next century through changes in primary production, soil carbon storage, and CH_4 emissions due to changes in the length of growing seasons, changes in soil moisture, and reductions in permafrost. As a result, anthropogenic emissions that cause warming will result in higher final greenhouse gas concentrations, and therefore more warming, than would be predicted in the absence of these ecosystem feedbacks. Because key ecological feedbacks to climatic change are unrepresented in GCMs, and because asymmetrical uncertainty about those feedbacks favors higher temperatures, it is likely that the future will be warmer than implied by present GCMs.

Climate Impacts Fish Recruitment by Affecting Larval Transport.[2] Scientists have developed a tool to predict how climate and weather affect the transport of fish larvae to their nursery areas. Fisheries biologists and physical oceanographers constructed a numerical model to predict the larval transport of an economically important flatfish, northern rock sole (*Lepidopsetta polyxystra*), in the southeastern Bering Sea based on their vertical position in the water column. Sustained shoreward transport during the 1980s led to a decade of above-average recruitment, and along-shelf or offshore transport in the 1990s resulted in a decade of below-average recruitment. This new model can now be used with Intergovernmental Panel on Climate Change climate projections to investigate the effects of changing climate on larval fish transport and recruitment due to changes in currents and regional wind patterns.

Complex Responses of Subalpine Forests to Climatic Change.[3] Changing climates in the 21st century are anticipated to significantly alter subalpine forest distributions. Studies of medieval paleoclimates and forest distribution shifts in the high Sierra Nevada, California, are revealing potential influences of future climate change. Tree-ring analysis and wood anatomy of deadwood preserved above current treeline (>3,000 m) has documented the existence of a mixed-conifer forest growing from AD 815 to 1350 on mountain summits in the eastern Sierra where currently no forests occur (see Figure 11).

***Pinus lambertiana* Preserved from a Medieval Forest**

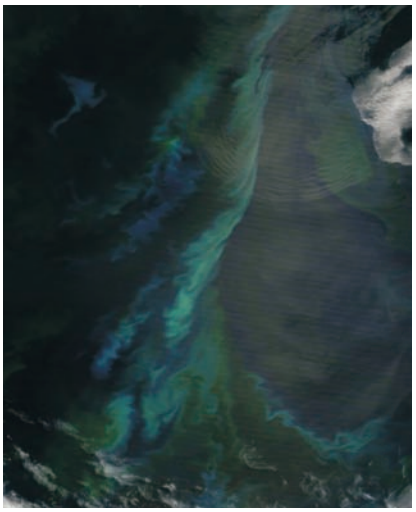
Figure 11: *Pinus lambertiana* Preserved from a Medieval Forest. Deadwood of sugar pine preserved from a medieval forest on Whitewing Mountain, eastern Sierra Nevada, California. The current range of this species is west of the Sierra crest (in background) and about 700-m lower in elevation. *Credit: C. Millar, USDA / Forest Service.*

The Medieval forest was composed of six species, including five whose current upper ranges are 200 to 500 m below the deadwood forest elevation in the eastern Sierra and one species that is now native only to the west slope of the Sierra Nevada at elevations more than 700 m below the deadwood location. Climates of the Medieval forest based on these data were significantly warmer (+3.2°C annual minimum temperature) and slightly drier (-24 mm annual precipitation) than present, values similar to those estimated for 2100 in the Sierra Nevada. The significant changes evidenced by the Medieval forest provide a case study of potential forest responses to be encountered in the future and indicate a much higher level of complexity than has been anticipated.

Climatic Synchronization of Periods of Prehistoric Widespread Forest Wildfires.[4] The ability of climate variation to synchronize widespread forest fires across much of western North America was recently documented for a multi-century period. During the past 400 years, the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) were the primary drivers of interannual to decadal variation in fire synchrony, whereas the Atlantic Multidecadal Oscillation (AMO) affected the strength of ENSO and PDO effects on wildfire synchrony at multidecadal scales. During certain phases of ENSO and PDO, fire was synchronous within broad subregions and sometimes asynchronous among those regions. In contrast, fires were most commonly

synchronous across the West during warm phases of the AMO. The research is the first to demonstrate that synchrony in forest wildfires across western North America is directly related to surface conditions of the Atlantic Ocean. Current shifts to positive AMO conditions imply a potential for increased wildfire synchrony during the next few decades, in addition to that attributed to global warming.

Invasive Species Patterns Track Those of Native Species.[5] A review of patterns of species richness (the number of species in a given area) and species density (the mean number of species per square kilometer) for both native species and non-indigenous or invasive species of plants, birds, and fishes in the continental United States and Hawaii shows that the species densities of native and non-indigenous species are positively correlated for plants, birds, and fishes. The correlations of species densities between native and non-indigenous plants and native and non-indigenous birds are especially strong ($r = 0.86$ and 0.93, respectively). Densities of non-indigenous plant and bird species are also highly predictable with the densities of native plant species and native bird species being by far the strongest predictive variables. These results support the hypothesis that, at least for plant and bird species, "the rich get richer," in that areas with high densities of native species tend to be more susceptible to invasion by non-indigenous species. For plant and bird taxa in the continental United States, biodiversity itself does not appear to act as a barrier to species invasions.



Estimates of Tropical Pacific Ocean Productivity Lowered.[6] Ten field studies over the years 1994 to 2006 collected more than 140,000 *in situ* measurements of the chlorophyll fluorescence characteristics of phytoplankton in the surface mixed layer of the tropical Pacific Ocean. These measurements allowed the delineation of three major ecophysiological regimes in the tropical Pacific based on the factors constraining phytoplankton growth, hence the primary productivity, of these regions. Iron has a key role in regulating phytoplankton growth in both high-nitrate low-chlorophyll and oligotrophic waters near the equator and further south, whereas nitrogen and zooplankton grazing are the primary factors that regulate biomass production north of the equatorial regions. Application of these findings to the interpretation of existing chlorophyll information derived from satellites shows that productivity in the tropical Pacific basin may be 1.2 to 2.5 GtC yr^{-1} lower than previous estimates have suggested, a difference that is comparable to the global change in ocean production that accompanied the largest El Niño to La Niña transition on record.

Coral Reef Management Guide.[7] A workshop of scientists and managers, co-led by several CCSP agencies under the auspices of the U.S. Coral Reef Task Force, resulted in compilation of *A Reef Manager's Guide to Coral Bleaching*. The combined research results among state/territorial, Federal, academic, nongovernmental, and international

scientists concluded that warming sea surface temperatures are a key factor in mass coral bleaching events. The *Guide* provides managers with strategies to support the natural resilience of coral reefs in the face of climate change.

Marine Pelagic Ecosystems: The West Antarctic Peninsula.[8] Penguins in the West Antarctic Peninsula are top consumers of marine resources, with diets of the most common species, the Adelie penguins, almost exclusively represented by one prey species, the Antarctic krill. The peninsula is experiencing some of the most rapid and significant warming on Earth, with two primary manifestations of change: the loss of sea ice and increased snow precipitation. One of the most striking responses is the change in penguin community composition during the last 3 decades, as ice-dependent and snow-intolerant Adelies have decreased while Chinstrap and Gentoo penguins have increased during a period of unprecedented environmental conditions (see Figure 12).

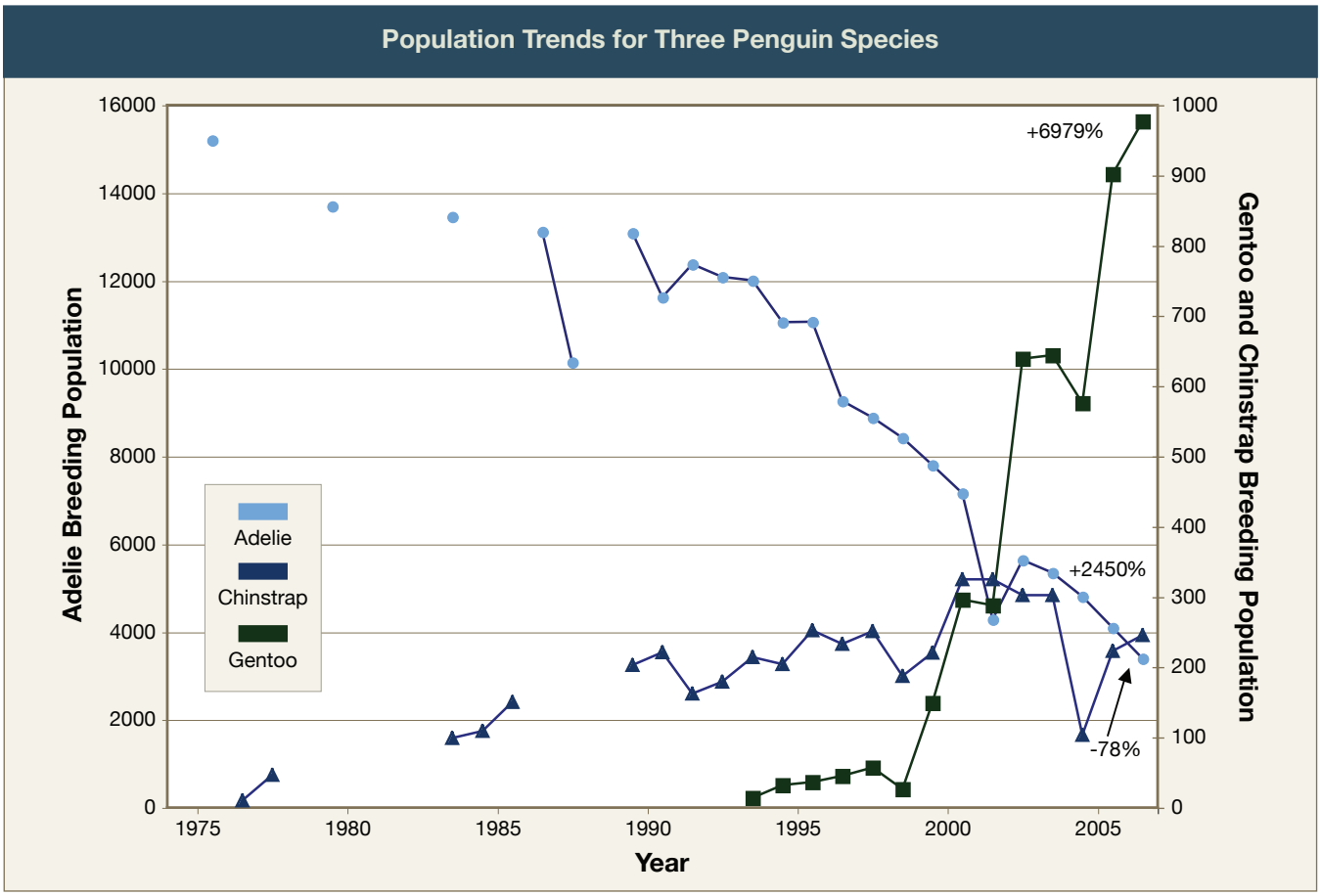


Figure 12: Population Trends for Three Penguin Species. Population trends for three penguin species in the Anvers Island vicinity, 1975 to 2006. The numbers on the graph indicate percentage change from initial sampling year for each species. *Credit: H. Ducklow, Marine Biological Laboratory; K. Baker and M. Vernet, University of California, San Diego; D.G. Martinson and S.E. Stammerjohn, Lamont-Doherty Earth Observatory; L.B. Quetin, R.M. Ross, and R.C. Smith, University of California, Santa Barbara; and W. Fraser, Polar Oceans Research Group (reproduced from* **Philosophical Transactions of the Royal Society B** *with permission from Royal Society Publishing).*

Nitrogen Limitation Constrains Sustainability of Ecosystem Response to CO_2.[9] Using free-air CO_2 enrichment technology in a prairie at the Cedar Creek Natural History Area in Minnesota, researchers in the BioCON (a long-term grassland project studying Biodiversity, CO_2 and N interactions) experiment found that some of Earth's plant life will not be able to sequester carbon from rising atmospheric CO_2 levels as well as scientists once thought. Instead, soil nutrients such as nitrogen will limit plant growth even when atmospheric CO_2 levels are higher. This study is the longest of its kind and consistent with other studies of trees and agricultural crops, providing evidence that nitrogen limitations may be common in the future in much of the world, despite widespread nitrogen pollution.

Highlights of Plans for FY 2008

CCSP will continue to gather and analyze information via experimental manipulation, measurement, modeling, and assessment studies to enhance understanding of ecosystems and of the processes affecting their changes. Key research plans for FY 2008 follow.

Effects of Changes in Precipitation on Southwestern Ecosystems. Climate models indicate that precipitation and soil moisture are likely to change in the southwestern United States during this century. To reduce scientific uncertainty about the potential effects of such changes on the structure and functioning of terrestrial ecosystems throughout the region, field experiments involving *in situ* manipulation of precipitation and soil moisture will be conducted in southwestern pinyon-juniper woodlands, coast sage, grassland, chaparral, and oak-pine forest ecosystems. Measurements will elucidate potential effects of altered precipitation on primary production processes, species diversity, decomposition of soil organic matter and related biogeochemistry, and aspects of ecological feedbacks to the physical climatic system.

This activity will address Questions 4.1, 5.4, 6.4, 7.5, 8.1, 8.2, and 9.2 of the CCSP Strategic Plan.

Improving Ecosystem Observations and Models. Current ecological, biogeochemical cycling, and climate models require more quantitative information on the variety, distribution, abundance, and temporal variability of terrestrial and marine groups of organisms having important physiological and ecological functions (e.g., key players in primary production, nitrogen fixers, invasive species). Planned activities for FY 2008 will focus on promoting abilities to detect attributes of these groups that can be derived through the analysis of continuous, high-resolution spectra spanning the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum. In

addition, more realistic and robust ecosystem models need to incorporate additional major drivers of ecosystem processes, especially drivers in the human system through the incorporation of socioeconomic information. Doing so will improve the realism of (1) regional and global ecological models and (2) ecological component models that link to climate, hydrological, and/or atmospheric models.

This activity will address Questions 8.1, 8.2, and 8.3 of the CCSP Strategic Plan.

Climate Impacts on Marine Ecosystems. Projects will be implemented to understand the responses of the physical environment and ecosystems to projected climate change scenarios and to develop predictions of the ecosystem impacts of these changes. These projects will collect observations, conduct research, and synthesize results to increase the understanding of regional climate impacts on marine ecosystems. This work will be conducted in conjunction with the development and refinement of biophysical indicators and models to provide living marine resource managers the knowledge and predictive tools necessary to adapt to the consequences of climate change for ecosystems.

This activity will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

ECOSYSTEMS CHAPTER REFERENCES

1) **Torn**, M.S. and J. Harte, 2006: Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming. *Geophysical Research Letters*, **33,** L10703, doi:10.1029/2005GL025540.
2) **Lanksbury**, J.A., J.T. Duffy-Anderson, K.L. Mier, M.S. Busby, and, P.J. Stabeno, 2007: Distribution and transport patterns of Northern rock sole, *Lepidopsetta polyxystra*, larvae in the southeastern Bering Sea. *Progress in Oceanography*, **72**, 39-62.
3) **Millar**, C.I., J.C. King, R.D. Westfall, H.A. Alden, and D.L. Delany, 2006: Late Holocene forest dynamics, volcanism, and climate change at Whitewing Mountain and San Joaquin Ridge, Mono County, Sierra Nevada, CA, USA. *Quaternary Research*, **66**, 273-287.
4) **Kitzberger**, T., P.M. Brown, E.K. Heyerdahl, T.W. Swetnam, and T.T. Veblen, 2007: Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. *Proceedings of the National Academy of Sciences*, **104**, 543-548.
5) **Stohlgren**, T.J., D. Barnett, C. Flather, P. Fuller, B. Peterjohn, J. Kartesz, and L.L. Master, 2006: Species richness and patterns of invasion in plants, birds, and fishes in the United States. *Biological Invasions*, **8**, 427-447.
6) **Behrenfeld**, M.J., K. Worthington, R.M. Sherrell, F.P. Chavez, P. Strutton, M. McPhaden, and D.M. Shea, 2006: Controls on tropical Pacific Ocean productivity revealed through nutrient stress diagnostics. *Nature*, **442**, 1025-1028.
7) **Marshall**, P.A. and H.Z. Schuttenberg, 2006: *A Reef Manager's Guide to Coral Bleaching*. Great Barrier Reef Marine Park Authority, Townsville, Australia.
8) **Ducklow**, H.W., K. Baker, D.G. Martinson, L.B. Quetin, R.M. Ross, R.C. Smith, S.E. Stammerjohn, M. Vernet, and W. Fraser, 2006. Marine pelagic ecosystems: the West Antarctic Peninsula. *Philosophical Transactions of the Royal Society B*, **362**, 67-94.
9) **Reich**, P.B., S.E. Hobbie, T. Lee, D.S. Ellsworth, J.B. West, D. Tilman, J.M.H. Knops, S. Naeem, and J. Trost, 2006. Nitrogen limitation constrains sustainability of ecosystem response to CO_2. *Nature*, **440**, 922-925.

7 Decision-Support Resources Development and Related Research on Human Contributions and Responses

CCSP Decision-Support Goals

Decision-Support Goal 1: Prepare scientific syntheses and assessments to support informed discussion of climate variability and change and associated issues by decisionmakers, stakeholders, the media, and the general public.

Decision-Support Goal 2: Develop resources to support adaptive management and planning for responding to climate variability and climate change, and transition these resources from research to operational application.

Decision-Support Goal 3: Develop and evaluate methods (scenario evaluations, integrated analyses, and alternative analytical approaches) to support climate change policymaking and demonstrate these methods with case studies.

Strategic Research Questions

9.1 What are the magnitudes, interrelationships, and significance of the primary human drivers of, and their potential impact on, global environmental change?

9.2 What are the current and potential future impacts of global environmental variability and change on human welfare, what factors influence the capacity of human societies to respond to change, and how can resilience be increased and vulnerability reduced?

9.3 How can the methods and capabilities for societal decisionmaking under conditions of complexity and uncertainty about global environmental variability and change be enhanced?

9.4 What are the potential human health effects of global environmental change, and what climate, socioeconomic, and environmental information is needed to assess the cumulative risk to health from these effects?

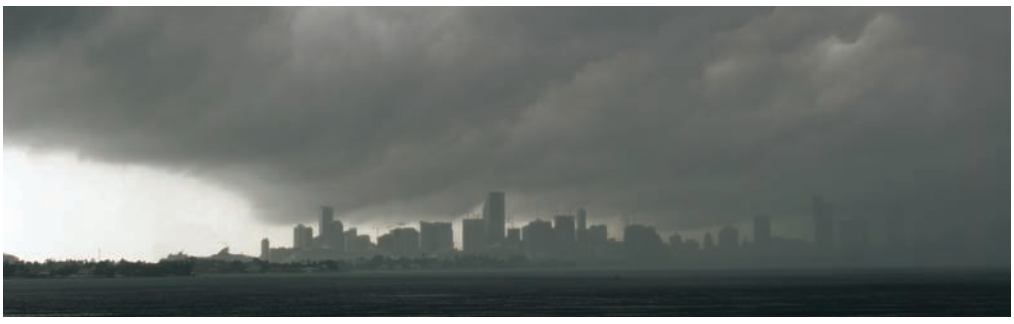
See Chapter 11 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of decision-support resources development and Chapter 9 for these specific research questions.

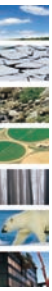
One of the main purposes of CCSP is to provide information for decisionmaking through the development of decision-support resources. Decision-support resources, systems, and activities are climate-related products or processes that directly inform or advise stakeholders to help them make decisions. These products or processes include analyses and assessments, interdisciplinary research, analytical methods (including scenarios and alternative analysis methodologies), model and data product development, forecasts, communication, and operational services. Decision-support resources and activities include research activities based in the natural sciences and activities related to human contributions and responses to climate variability and change, such as demography, economics, history, anthropology, political science, and sociology.

Decision Support Goal 1: Scientific Syntheses and Assessments

The *CCSP Strategic Plan* defines "assessments" as "processes that involve analyzing and evaluating the state of scientific knowledge (and the associated degree of scientific certainty) and, in interaction with users, developing information applicable to a particular set of issues or decisions." Assessments are an effective means for integrating and analyzing CCSP research results with other knowledge, and communicating useful insights in support of a variety of applications for decision support. Assessments also help identify knowledge gaps and thus provide valuable input to the process of focusing research.

A primary activity within CCSP is the development of 21 synthesis and assessment products (SAPs) to support informed decisionmaking on climate variability and change by a broad group of stakeholders, including policymakers, resource managers, media, and the general public. The development of these SAPs stems from the Global Change Research Act (GCRA) of 1990 (P.L. 101-606, section 106), which directs the program to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic science "assessments."





DESCRIPTION OF CCSP SYNTHESIS AND ASSESSMENT PRODUCTS

CCSP Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and changes.

Synthesis and Assessment Product 1.1

Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences

Temperature change is a fundamental measure of climate change. This product, which was the first to be completed, addresses temperature changes from the surface through the lower stratosphere and understanding of the causes of these changes. It assesses progress made since the reports by the National Research Council (2000) and the Intergovernmental Panel on Climate Change (2001) and highlights differences between the individual temperature records determined by components of the existing observational and modeling systems and documents the potential causes of these differences.

Synthesis and Assessment Product 1.2

Past Climate Variability and Change in the Arctic and at High Latitudes

The Arctic and the high latitudes have warmed more rapidly than almost any other region on Earth over at least the last millennium. This warming has been accompanied by a decrease in sea ice cover and thickness and a decrease in ocean salinity. In addition, significant changes in the permafrost active layer are now being detected. The impacts on humans and ecosystems that are associated with these changes were reported in the *Arctic Climate Impact Assessment*, which was partially funded by CCSP-participating agencies. The present synthesis and assessment product on the Arctic and high latitudes will focus on the state of knowledge concerning past changes in the physical climate of this region and the implications of this record of past changes for current and future change. This information is vital since high-latitude regions are projected to continue to experience the greatest warming in the future.

Synthesis and Assessment Product 1.3

Reanalyses of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change

A reanalysis is a detailed, retrospective study of the state of the atmosphere using a consistent numerical model of the dynamics of the system and based on observations for the time period of the study. This product provides an assessment of the capability and limitations of state-of-the-art climate reanalysis to describe past and current climate conditions, and the consequent implications for scientifically interpreting the causes of climate variations and change. The product will be in the form of a report that summarizes the present status of national and international climate reanalysis efforts, and discusses key research findings on the strengths and limitations of current reanalysis products for describing and analyzing the causes of climate variations and trends that have occurred during the time period of the reanalysis records (roughly the past half-century). The report will describe how reanalysis products have been used in documenting, integrating, and advancing our knowledge of climate system behavior, as well as in ascertaining significant remaining uncertainties in descriptions and physical understanding of the climate system.

CCSP Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Synthesis and Assessment Product 2.1

Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations, and Review of Integrated Scenario Development and Application

This product, which was publicly released in 2007, provides a new long-term, global reference for greenhouse gas stabilization scenarios and an evaluation of the process by which scenarios are developed and used. SAP 2.1 consists of two parts. Part A, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*, uses computer-based scenarios to evaluate four alternative stabilization levels of greenhouse gases in the atmosphere and the implications for energy and the economy of achieving each level. Part A includes stabilization scenarios for the six primary anthropogenic greenhouse gases—carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride—and it uses updated economic and technological data and new tools for scenario development. Although these scenarios should not be considered definitive predictions of future events, they provide valuable insights for decisionmakers. Part B, *Global Change Scenarios: Their Development and Use*, examines how scenarios have been developed and used in global climate change applications, evaluates the effectiveness of current scenarios, and recommends ways to make future scenarios more useful. Part B of the report concludes that scenarios can support decisionmaking by providing insights regarding key uncertainties, including future emissions and climate as well as other environmental and economic conditions.

DESCRIPTION OF CCSP SYNTHESIS AND ASSESSMENT PRODUCTS (CONT.)

CCSP Goal 2 (continued)

SYNTHESIS AND ASSESSMENT PRODUCT 2.2

North American Carbon Budget and Implications for the Global Carbon Cycle

This product provides a synthesis and integration of the current knowledge of the North American carbon budget (including land, atmosphere, inland waters, and adjacent oceans) and its context within the global carbon cycle. In a format useful to decisionmakers, it summarizes knowledge of carbon cycle properties and changes relevant to the contributions of, and impacts upon, the United States and the rest of the world; and provides scientific information for U.S. decision support focused on key issues for carbon management and policy. It addresses carbon emissions; natural reservoirs and sequestration; rates of transfer; the consequences of changes in carbon cycling; effects of purposeful carbon management; effects of agriculture, forestry, and natural resource management; and socioeconomic drivers and consequences. The report includes an analysis of North America's carbon budget that documents the state of knowledge and quantifies uncertainties.

SYNTHESIS AND ASSESSMENT PRODUCT 2.3

Aerosol Properties and their Impacts on Climate

Aerosols can cause a net cooling or warming within the climate system, depending upon their physical and chemical characteristics. In addition to these direct effects, aerosols can also have indirect effects on radiative forcing of the climate system by changing cloud properties. The first phase of development of this product is to produce major scientific reviews of the following three topics: dependence of radiative forcing by tropospheric aerosols on aerosol composition in the north Atlantic, Pacific, and Indian Ocean regions; measurement-based understanding of aerosol radiative forcing from remote-sensing observations; and model intercomparison to quantify uncertainties associated with indirect aerosol forcing. The second-phase product will draw upon the scientific information gathered by the development of the Intergovernmental Panel on Climate Change Fourth Assessment Report and the National Research Council review, *Radiative Forcing of Climate Change*. These community-wide assessments of climate change (and the aerosol-climate topic inclusively) will be drawn from in writing SAP 2.3.

SYNTHESIS AND ASSESSMENT PRODUCT 2.4

Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure

Measurements of ozone-depleting gases in the atmosphere have shown that the concentrations of these gases are declining in response to the agreements reached under the Montreal Protocol. This report will provide an update on trends in stratospheric ozone, ozone-depleting gases, and ultraviolet radiation exposure; progress in improving model evaluations of the sensitivity of the ozone layer to changes in atmospheric composition and climate; and relevant implications for the United States. This information is key in ensuring that international agreements to phase out production of ozone-depleting substances are having the expected outcome—recovery of the protective ozone layer. The report will derive most of its information from recent international assessments of stratospheric ozone, ozone-depleting substances, and climate.

CCSP Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

SYNTHESIS AND ASSESSMENT PRODUCT 3.1

Climate Models: An Assessment of Strengths and Limitations

The topics addressed by this product are the strengths and limitations of climate models at different spatial and temporal scales. Its purpose is to provide information on the results from climate models, in ways that will allow the potential user of the information to evaluate how best it may be applied. The product will focus on natural and human-caused factors influencing climate variability and change during the period from 1870 to 2000. It will characterize sources of uncertainty in climate models and their implications for estimating future climate change. This product will be limited to the models and their sensitivity, feedbacks, strengths, and limitations, rather than making specific future projections.

SYNTHESIS AND ASSESSMENT PRODUCT 3.2

Climate Projections for Research and Assessment Based on Emissions Scenarios developed through the Climate Change Technology Program

This product will have two distinct components. The first will be to produce climate projections for research and assessment based on greenhouse gas emission scenarios and atmospheric concentrations as reported in SAP 2.1a. The second will be to assess the future climate impacts of short-lived gaseous and particulate species.

DESCRIPTION OF CCSP SYNTHESIS AND ASSESSMENT PRODUCTS (CONT.)

CCSP Goal 3 (continued)

SYNTHESIS AND ASSESSMENT PRODUCT 3.3

Weather and Climate Extremes in a Changing Climate: North America, Hawaii, Caribbean, and U.S. Pacific Islands

The impact of climate extremes can be severe and wide-ranging. There is evidence that the economic impact of weather and climate extremes in the United States has increased over the past several decades, but the evidence for increases in extreme weather and climate events varies depending on the event of interest. These events may be related to temperature parameters (severe freezes, heat waves), precipitation (wet spells, heavy precipitation events, droughts, ice and hail, snow cover and depth), or tropical and extratropical storm frequency. Identifying recent changes and trends in such parameters will be a focus of the report, as well as identifying what can be said about future changes. Since extreme weather and climate events on a global scale are regularly addressed in international assessments, this product will focus on weather and climate extremes primarily across Canada, Mexico, and the United States.

SYNTHESIS AND ASSESSMENT PRODUCT 3.4

Abrupt Climate Change

The paleoclimate record reveals that Earth's climate can change rapidly and strongly between different stable states. Various scenarios portray future abrupt climate change large enough to pose a significant challenge to society. The goal of this product is to review and synthesize our current understanding of abrupt climate change and to identify gaps in our knowledge. The report will integrate information from the paleoclimate record, the instrumental record, and numerical model-based studies at various spatial scales. Key identified risks, such as changes in ocean thermohaline circulation and alteration of terrestrial hydrologic conditions (e.g., the location or amount of precipitation) will receive special attention because the potential impacts on society are large.

CCSP Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

SYNTHESIS AND ASSESSMENT PRODUCT 4.1

Coastal Elevation and Sensitivity to Sea-Level Rise

This product will examine the vulnerability of coastal areas in the U.S. mid-Atlantic states to sea-level change. Specific questions to be addressed include identifying which areas are low enough to be inundated by tides, how floodplains would change due to a changing climate, which areas might be subject to erosion, and locations where wetlands will be able to migrate inland versus locations where shores will be protected. The product will examine the implications of sea-level rise, including impacts on population and economic activity in vulnerable areas, costs of shore protection, ecological effects, flood damages, public access to modified shore areas, cases where sea-level rise justifies policy changes, options being considered by conservancies and governments, and lessons from the unfolding consequences of the 2005 hurricanes in the Gulf Coast region.

SYNTHESIS AND ASSESSMENT PRODUCT 4.2

Thresholds of Change in Ecosystems

There is a body of ecosystems research that focuses on enhancing understanding of climate change impacts on ecosystems (and *vice versa*) and developing the capability to predict potential impacts of future climate change. Increasing emphasis is being placed on climate-related thresholds that could result in discontinuities or sudden changes in ecosystems and climate-sensitive resources. Discontinuities in responses of ecosystems and resources are difficult to predict, and may significantly affect human societies that depend on ecosystem goods and services. Improved understanding of such sudden changes is essential to managing ecosystems and resources in the face of climate change. This report will synthesize the present state of scientific understanding regarding thresholds of change that trigger sudden changes in ecosystems and climate-sensitive resources. The report will develop a conceptual framework for characterizing sudden changes, and synthesize peer-reviewed studies that provide the best available evidence for defining circumstances that trigger discontinuities in response to climate change.

SYNTHESIS AND ASSESSMENT PRODUCT 4.3

The Effects of Climate Change on Agriculture, Biodiversity, Land, and Water Resources

This report will address the effects of climate change on agriculture, forestry, land and water resources, and biodiversity. Air and water temperature, precipitation, and related climate variables are fundamental regulators of biological processes. For this reason, human-induced climate change has the potential to affect the condition, composition, structure, and function of ecosystems. Such changes may also alter the linkages and feedbacks between ecosystems and the climate system. Additionally, ecosystems produce a wide array of goods and services valued by humans and in many cases essential for human survival and property. Climate-related changes in ecosystems and other key resources could have impacts on human communities and economic conditions.

DESCRIPTION OF CCSP SYNTHESIS AND ASSESSMENT PRODUCTS (CONT.)

CCSP Goal 4 (continued)

Synthesis and Assessment Product 4.4

Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources

Climate is a dominant factor influencing the distribution, abundance, structure, and function of, and services provided by, ecosystems. Many ecosystems are thus vulnerable to future changes in climate. The goal of adaptation is to reduce these risks of adverse ecological outcomes through management activities that increase the resilience of these systems to climate change. Resilience is defined here as the magnitude of disturbance that can be absorbed by a system before it shifts from one stable state (or stability domain) to another and the speed of return of a system to equilibrium after a disturbance has occurred. This report will provide a review and synthesis of information on adaptation options for selected climate-sensitive ecosystems in order to aid in designing management strategies that facilitate adaptation, provide examples of how to implement strategies in specific places, and identify issues and challenges associated with implementation of adaptation options.

Synthesis and Assessment Product 4.5

Effects of Global Change on Energy Production and Use in the United States

This report summarizes what is currently known about potential effects of climatic change on energy production and use in the United States. It focuses on three questions: (1) How might climatic change affect energy use in the United States, (2) how might climatic change affect energy production and supply in the United States, and (3) how might climatic change have other effects that indirectly shape energy production and use in the United States? Great care is being taken in answering these questions, for two reasons. One, the available research literatures on these key questions is limited, supporting a discussion of issues but not providing definite answers. Two, as with many other aspects of potential effects of climatic change on the United States, the effects on energy production and use depend on more than climatic change alone; other potentially important factors include patterns of economic growth and land use, patterns of population growth and distribution, technological change, and social and cultural trends that could shape policies and actions, individually and institutionally.

Synthesis and Assessment Product 4.6

Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems

Synthesis and Assessment Product 4.6 will examine the effects of global change on human systems. This product will address Goal 4 of the five strategic goals in the *CCSP Strategic Plan* to "understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes." The impacts of climate variability, climate change, shifting patterns of land use, and changes in population patterns are human problems, not simply problems for the natural or the physical world. This SAP will examine the vulnerability of human health and socioeconomic systems to global environmental change across three areas of potential impacts and adaptations: human health, human settlements, and human welfare. This product will address the questions of what, where, and when climate variability and change will affect U.S. social systems. The challenge for this project will be to assess risks associated with health, welfare, and settlements and to identify and develop timely adaptive strategies to address human vulnerabilities. The primary goals for adaptation to climate change and variability focus on managing significant risks proactively when possible; establishing protocols to detect and measure risks; and leveraging technical and institutional adaptive capacity to address new climate risks, especially as they exceed conventional adaptive measures.

Synthesis and Assessment Product 4.7

Impacts of Climate Variability and Change on Transportation Systems and Infrastructure: Gulf Coast Study

This product will address the potential effects of climate variability and change on transportation infrastructure and systems in the central Gulf Coast of the United States. The purpose of this study is to increase the knowledge base regarding the risks and sensitivities of transportation infrastructure to climate variability and change, the significance of these risks, and the range of adaptation strategies that may be considered to ensure a robust and reliable transportation network. Implications for all transportation modes—surface, marine, and aviation—will be addressed. The three-phase study will focus on the Gulf Coast, and will assess the significant risks to transportation, develop methodology to be applied in other geographic locations, identify potential strategies for adaptation, and develop decision-support tools to assist transportation decisionmakers in incorporating climate-related trend information into transportation system planning, design, engineering, and operational decisions.

DESCRIPTION OF CCSP SYNTHESIS AND ASSESSMENT PRODUCTS (CONT.)

CCSP Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

Synthesis and Assessment Product 5.1

Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions

The product will focus on characterizing a subset of the observations from remote-sensing and *in situ* instrumentation that are of high value for decisionmaking. The product will characterize observational capabilities that are currently or could potentially be used in decision-support tools, catalog a subset of ongoing decision-support activities that use these capabilities, and evaluate a limited number of case studies of these decision-support activities. The detailed evaluation of decision-support activities and demonstration projects will provide information to agencies and organizations responsible for developing, operating, and maintaining selected decision-support processes and tools. The evaluation will also provide information on the nature of interactions between users and producers of climate science information, approaches for accessing science information, and assimilation of scientific information in the decisionmaking process. The product will include an online catalog of decision-support demonstration projects with interactive links, which will be updated as additional experiments are conducted and new approaches to incorporating and benchmarking application of observations and other global change research products evolve.

Synthesis and Assessment Product 5.2

Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decisionmaking

This product will address the issue of uncertainty and its relationship to science, assessment, and decisionmaking. Specifically, the product is intended to help improve the quality and consistency of information about scientific uncertainty presented to decisionmakers and other users of CCSP reports by identifying "best practice" options recommended in the literature on this subject; to improve communication between scientists and users of the products by providing recommendations for addressing uncertainty; and to provide a brief overview of the literature on approaches for communicating and considering uncertainty related to climate.

Synthesis and Assessment Product 5.3

Decision-Support Experiments and Evaluations Using Seasonal-to-Interannual Forecasts and Observational Data

This product will concentrate on the water-resource management sector. It will describe and evaluate current forecasts, assess how forecasts are being used in decision settings, and evaluate decisionmakers' level of confidence in these forecasts. The participants in the development of this product (primarily consisting of government officials, researchers, and users) will evaluate forecasts as well as their delivery, to identify options for improving partnerships between the research and user communities. It will inform decisionmakers about the experiences of others who have experimented with the use of seasonal and interannual forecasts and other observational data; climatologists and social scientists about how to advance the delivery of decision-support resources that use the most recent forecast products, methodologies, and tools; and science managers as they plan for future investments in research related to forecasts and their role in decision support.

As of September 2007, the following synthesis and assessment products have been released:

1.1 *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*

2.1 *A. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations* and *B. Global-Change Scenarios: Their Development and Use.*

Several other SAPs are expected soon. The accompanying box provides a brief description of the scope of each product. Up-to-date status on all SAPs can be found at <www.climatescience.gov/Library/sap/sap-summary.php>.

CCSP supports research and tool development that focus on human behavior and socioeconomic trends. Assessments need to incorporate projections of social and economic change (e.g., population and technological change), as well as the effects of

environmental change on communities and sectors (e.g., transportation, health, agriculture). Decision support also requires methods and tools to undertake comparative work across communities, regions, and sectors.

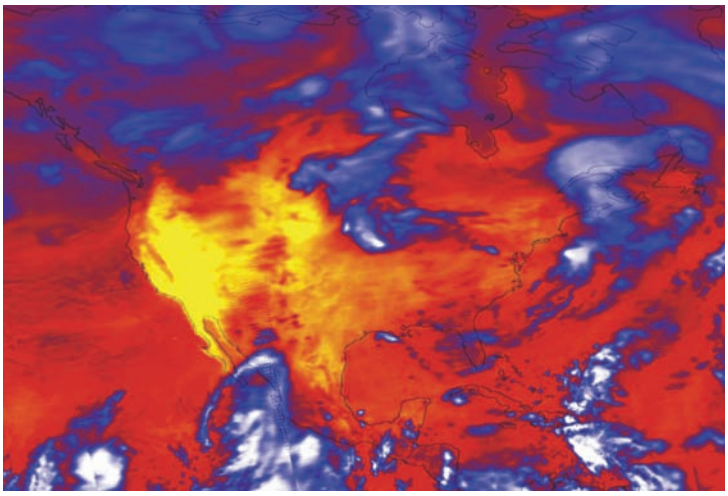
Decision Support Goal 2: Adaptive Management and Planning Decisions

A number of efforts are underway to support adaptive management and planning decisions (operational decisions for managing resources, societal response mechanisms, and long-term infrastructure planning). These activities involve sectoral analyses examining agriculture, forestry, water supply, fisheries, and human health. Drought and variations in the frequency of temperature extremes, severe precipitation, and runoff are key climate challenges being addressed. Progress is being made to engage stakeholders at local and regional levels in an effort to bring information about the impacts of climate variability and change to bear on their management and planning decisions. Bringing climate science to decisionmakers, analyzing the impacts of climate on their decisions, and collaborating with them to produce new knowledge and tools are all key parts of this goal.

Decision Support Goal 3: Methods to Support Climate Policymaking

Climate is a primary or significant factor in policy considerations, such as options for reducing greenhouse gas emissions, long-term ecosystem management, and infrastructure planning. CCSP, in collaboration with the CCTP, is providing useful information related to these issues.

CCSP also supports the development of integrated modeling frameworks that are useful for exploring many dimensions of climate and global change. Full integration of information on human activities, greenhouse gases and aerosol emissions, land-use and land-cover change, cycling of carbon and other nutrients, climatic responses, and impacts on people, the economy, and resources is necessary for analysis of many important questions about the potential economic and environmental implications of changing greenhouse gas concentrations and alternative technology portfolios. Answers from integrated analysis can only reflect the existing



state of knowledge, but it is important to develop frameworks and resources for integration, exercise them, and learn from analysis of the results. CCSP is encouraging innovation and development of approaches to integrated analysis.

Highlights of Recent Research

Selected highlights of recent research and activities supported by CCSP-participating agencies follow

The National Research Council's Committee on the Human Dimensions of Global Change. An important source of scientific expertise and judgment on societal issues related to global change is the Committee on the Human Dimensions of Global Change (CHDGC) of the National Research Council (NRC). The committee was formed in 1989, to help guide U.S. research on the interactions between human activity and global environmental change. The CHDGC focuses on two main tasks: developing the intellectual basis for progress in understanding human-environment interactions, and advising on future research directions. Recently completed and soon-to-be-completed studies include:

- *Analysis of Global Change Assessments: Lessons Learned.* Global change assessments inform decisionmakers about the scientific underpinnings of a range of environmental issues. With dozens of assessments conducted to date by various U.S. and international groups, this report took the opportunity to draw on these experiences to improve future efforts. The report, which was produced by the NRC Board on Atmospheric Sciences and Climate and was released in February 2007, identifies 11 essential elements of effective assessments and provides recommendations on evolving the process to better support decisionmaking.
- *Public Participation in Environmental Assessment and Decisionmaking.* This report will use available research and experience and some specially commissioned studies in order to draw conclusions and recommendations about how best to implement broader public participation in environmental assessment and policymaking. The

study seeks to specify indicators of success and variables believed to influence these indicators; identify lessons from experience concerning which approaches work well under which conditions; state testable hypotheses that would allow verification or refinement of the lessons drawn from currently available information; and propose ways for government agencies to learn systematically from their own experience and the experience of others.

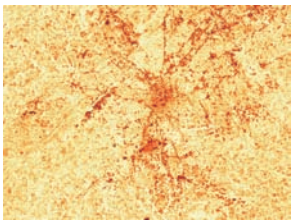
- *Putting People on the Map: Protecting Confidentiality with Linked Social-Spatial Data.* Precise, accurate spatial information linked to social and behavioral data is revolutionizing social science by opening new questions for investigation and improving understanding of human behavior in its environmental context. At the same time, precise spatial data make it more likely that individuals can be identified, breaching the promise of confidentiality made when the data were collected. Because norms of science and government agencies favor open access to all scientific data, the tension between the benefits of open access and the risks associated with potential breach of confidentiality pose significant challenges to researchers, research sponsors, scientific institutions, and data archivists. *Putting People on the Map*, a CHDGC report released in March 2007, finds that several technical approaches for making data available while limiting risk have potential, but none is adequate on its own or in combination.

New Alaska Center for Climate Assessment and Policy.[1] A new Regional Integrated Sciences and Assessments (RISA) effort focused on Alaska was launched in September 2006. The new Alaska Center for Climate Assessment and Policy (ACCAP) will synthesize data and information to quantify the effects of changes in seasonality of weather and climate on Alaskan people and ecosystems, determine stakeholder needs for enhanced information, conduct research to facilitate product enhancement, and assess vulnerability and adaptive capacity of various Alaskan sectors. Transportation will provide the initial focus for these activities. Federal partners include NOAA and the U.S. Bureau of Land Management; other partners include nongovernmental organizations, state agencies, tribal governments, and the private sector.

National Integrated Drought Information System Program Office. In support of the Western Governors Association report, *Creating a Drought Early Warning System for the 21st Century: The National Integrated Drought Information System*, and the National Integrated Drought Information System (NIDIS) Authorization Bill signed in 2006, the interagency NIDIS program office has been established. The goal of NIDIS is to create an interagency and interstate coordination program to (1) improve public awareness of drought and attendant impacts, (2) improve the capacity of counties and watershed organizations to reduce drought risks proactively, and (3) provide guidance on filling information gaps including those for monitoring, forecasting, and impact

assessments as needed. The interagency NIDIS Implementation Plan, which addresses these three goals, was released in 2007.

Climate Change Impacts on Agricultural Efficiency in Central America. Over the last decade, there has been engagement in developing criteria and tools for assessing the potential effects of climate change and climate variability on agricultural systems, natural ecosystems, and other systems and sectors worldwide. The present task is to apply those tools in key regions to provide policymakers and practitioners in various affected countries with the means to anticipate, mitigate, and/or adapt to changes in the mean values and potential extremes of a changing climate. An exploratory study of the effects of climate change on agricultural efficiency in the state of Costa Rica will be undertaken. Costa Rica lies at the center of the climate-sensitive Isthmus of Central America. One scenario product that will be developed in this research effort involves the use of global climate models to determine how storm tracks may change in both the Pacific and Caribbean subregions of Central America.

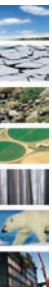


Environmental Public Health Tracking Network.[2] CCSP scientists have been working with the Centers for Disease Control and Prevention (CDC) and partners in environmental public health to provide environmental data products that would be of benefit to the Environmental Public Health Tracking Network (EPHTN). EPHTN will establish a national network of local, state, and Federal public health agencies to track trends in priority non-infectious health effects. This effort is being undertaken as part of the Health and Environment Linked for Information Exchange in Atlanta (HELIX-Atlanta) project. This effort is demonstrating a process for developing a local environmental public health tracking (surveillance) network. In a 2006 report, it was found that augmenting the EPA Air Quality System (AQS) observations with NASA Moderate Resolution Imaging Spectroradiometer (MODIS)-derived $PM_{2.5}$ (particulate matter that is 2.5 μm or smaller in size) observations increases the temporal and spatial resolutions of fine particulate estimates. The report also found that such augmentation also increases the accuracy in estimating concentrations of an environmental hazard such as $PM_{2.5}$, which is absolutely critical for environmental public health tracking. High concentrations of $PM_{2.5}$ are associated with adverse health reactions (e.g., respiratory and cardiovascular problems).

Representation of Expectations in Assessment Models. One source of divergence among alternative economic models in assessments of emissions mitigation is the way the models represent expectations of future developments—that is, whether current decisions are based on future as well as current conditions (i.e., the model is forward-looking) or each time period is analyzed independently (i.e., recursive dynamic). To provide a basis for studying these differences in approach, the Massachusetts Institute

of Technology (MIT) Joint Program on the Science and Policy of Global Change has completed the development of a forward-looking version of its Emissions Prediction and Policy Analysis (EPPA) model, which was originally developed in a recursive-dynamic form. Application of the two versions to the same set of mitigation proposals allows a direct comparison of methods. In terms of timing of mitigation efforts, the two versions show similar results but the macroeconomic effects of mitigation are smaller in the forward-looking model because it optimizes over time, and smoothes out bumps in the consumption path. Solving the forward-looking model is computationally demanding, and to do so requires simplifications that reduce the model dimensions, such as the number of regions, sectors, or time steps. The fact that the recursive and the forward-looking versions give similar results in terms of mitigation allows for continued use of the recursive model where a longer time horizon or greater regional detail is required.

New Local 3-Month Temperature Outlook.[3] A new climate forecast product, the Local 3-Month Temperature Outlook (L3MTO), was released in 2007. This product represents years of development by climate services personnel utilizing climate forecasting best practices from the Climate Prediction Center. This product also leverages extensive research from the RISA program on communicating probabilistic information to diverse decisionmakers to help them make economically, socially, and environmentally sound decisions. L3MTO is presented in various levels of complexity for different types of users. It incorporates copious help documentation as well as users' guides. Comments and feedback have been used to improve L3MTO and will continue to be addressed in the future. Plans call for expansion of the product suite to include precipitation in the near future. Figure 13 provides an example of this product.



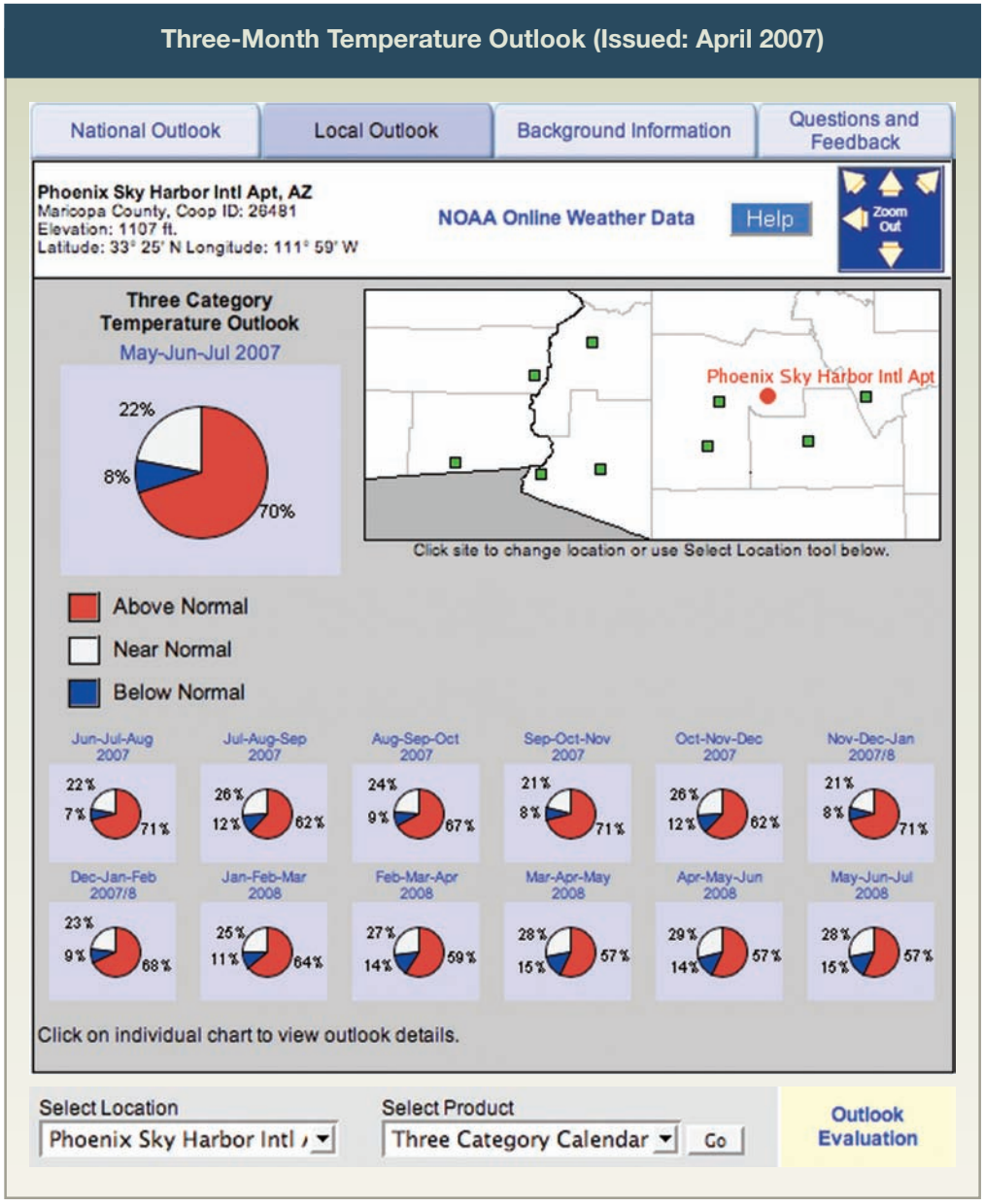


Figure 13: Three-Month Temperature Outlook (Issued: April 2007). This screenshot provides an example of a local 3-month temperature outlook (L3MTO) forecast for Phoenix, Arizona, and vicinity. *Credit: J. Bollinger, NOAA / National Weather Service.*

Projected Energy Usage in a Warmer Future.[4] Gradually increasing temperatures will create a greater demand for air conditioning and, in turn, a greater demand for energy and greater demand for coal to fuel power plants to produce the needed energy. A recent analysis of the effects of future projected climate change on energy usage and costs for the period 2000 to 2025 uses a numerical economic model driven with output from a climate model. The economic model includes data on building codes and census figures from every county in the United States, along with expected population changes during the time period. The coupling of a global climate model

with output at regional scales with state-of-the-art economic modeling to assess the effects of future climate change on energy use makes this study noteworthy.

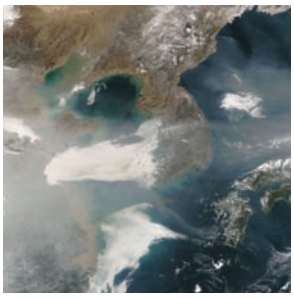
Highlights of Plans for FY 2008

New Regional Integrated Sciences and Assessments Effort Focused on Drought.[5] Under the auspices of the Coping with Drought through Research and Regional Partnerships effort described in the FY 2007 edition of *Our Changing Planet*, a new activity will be initiated in a region not currently covered by the RISA program. This new RISA activity will have drought impacts research and stakeholder work as a central theme and will provide an avenue within the region chosen for interagency work focused on climate impacts.

This activity will address Question 9.2 of the CCSP Strategic Plan, and will support Decision-Support Objective 2.1.

Development of Modeling Tools to Support Water and Watershed Management. Climate change presents a range of risks and opportunities to water managers. To minimize risk and take advantage of opportunities, tools are necessary to promote adaptive and forward-looking environmental management by decisionmakers at all levels. In 2007, a new climate assessment capability was developed within the Better Assessment Science Integrating Point and Non-point Sources (BASINS) watershed modeling system. The new tool facilitates assessment of the influence of climate variability and change on water quantity and quality and provides a capacity to evaluate adaptation strategies that increase the resilience of water systems to changes in climate. A case study using the new BASINS system is underway to assess the sensitivity of hydrologic and water quality endpoints to climate change in the Monocacy River watershed, a tributary to the Potomac River and Chesapeake Bay. An online decision support capability with the USDA ARS Water Erosion Prediction Project (WEPP) soil erosion model also is under development. New climate change assessment capabilities within WEPP will enable land managers to develop best management practices to lessen the impacts of climate variability and change on sediment loading from agricultural land to streams. In FY 2008, the need for developing similar climate assessment capabilities for models applicable to urban drainage and design will be determined.

This activity will address Questions 9.2 and 9.3 of the CCSP Strategic Plan, and will support Decision-Support Objectives 1.2 and 2.1.



Decision Assessment in the Gulf Coast and Chesapeake Bay Regions. Several pilot studies in the Gulf Coast region and the Chesapeake Bay were initiated to test different approaches to assessing the flow and use of climate change science information in decisionmaking, the factors and institutions that affect its use, and the types and characteristics of decisions most sensitive to climate change and most in need of additional re-evaluation and research in light of projected changes. Plans are to evaluate the results of these pilot studies to determine the applicability of a decision assessment approach to decisions related to water quality, aquatic ecosystems, and air quality.

This activity will address Question 9.3 of the CCSP Strategic Plan, and will support Decision-Support Objectives 2.1 and 3.2.

Integrated Evaluation of Climate Change, Mitigation, Bioenergy, and Land Use. Biofuels represent a potentially important source of energy that, depending on how they are produced, could reduce carbon dioxide (CO_2) emissions by replacing fossil fuels. However, greatly expanded use of biofuels would put pressure on food and forestry prices and could lead to conversion of land and release of carbon from soils and vegetation. At the same time, changes in climate, CO_2 levels, and concentrations of other pollutants such as ozone will affect the productivity of crops, pasture, and forestland. The MIT Joint Program on the Science and Policy of Global Change will complete linkage of a multi-sector, multi-region general equilibrium model of the world economy with a terrestrial ecosystem model that simulates biogeochemical processes of land systems at a 0.5° latitude-longitude grid level. The linkage will allow examination of the effects on greenhouse gas cycles of disturbances associated with the conversion of unmanaged forest and grassland to crop, pasture, or bioenergy production. Also, because it will be fully integrated with economic projections, the linked system will provide the ability to evaluate the feedbacks of changing environmental conditions on agricultural productivity, the resultant effects on the global and regional economy, consequent impacts on land use, and the further effects of land-use change on biogeochemical cycles and feedbacks on atmospheric composition and climate.

This activity will address Question 9.1 of the CCSP Strategic Plan, and will support Decision-Support Objective 3.1.

Integrated Impacts on and Adaptation to Climate Change of Terrestrial Ecosystems, Water Resources, and Agriculture. Terrestrial ecosystems, water resources, and agriculture represent important systems and pathways through which climate change could be experienced. Integrated models of drivers and systems response have generally lagged progress on the discrete research topics and associated models. In FY 2008, the foundations will be laid for incorporating these features into an integrated model in a way that reflects the state-of-the-art in relevant disciplinary research. Scoping meetings will be conducted to explore the state-of-the-art, identify methods for incorporation, and deliver a research plan. In addition, first steps will be taken to implement that

plan, including a preliminary evaluation of climate impacts on water resources with implications for agricultural impacts and adaptation.

This activity will address Question 9.2 of the CCSP Strategic Plan, and will support Decision-Support Objectives 2.1 and 3.1.

Scale and Timing of Climate Forcing. General circulation models, including those with coupled oceans and integrated terrestrial carbon cycles and atmospheric chemistry models, require time-dependent trajectories of greenhouse gases, chemically active gases, and aerosols to be run in forecast mode. In FY 2008, researchers will build on work reported in CCSP's SAP 2.1a to develop time-dependent trajectories that can be used by climate and atmospheric chemistry models.

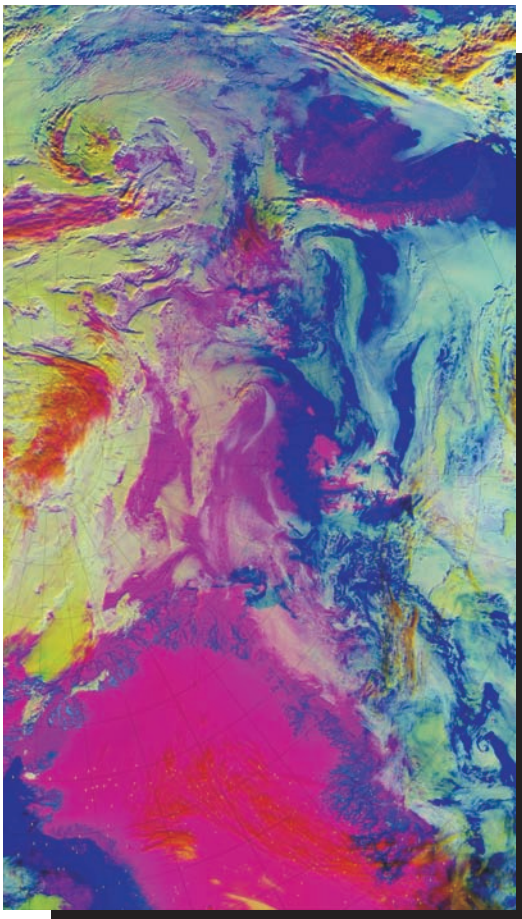
This activity will support Decision-Support Objectives 1.2 and 3.1.

Upcoming Report from the Committee on the Human Dimensions of Global Change. CHDGC is expected to release *Strategies and Methods for Climate-Related Decision Support* in FY 2009. This report will elaborate a framework for organizing and evaluating decision-support activities for CCSP, with special attention to sectors and issues of concern to the sponsors. It will also consider needs for science in support of decisions related to natural disasters and natural extreme events associated with climate change, such as droughts, floods, and hurricanes. To do this, the study panel will consider the range of relevant decisions, decisionmakers, decision contexts, spatial and temporal frames, and decision-support objectives, and current and potential strategies for organizing decision-support efforts to meet these objectives—taking into account the fact that, in some sectors, the desired outcomes of decision-support activities may not be clear in advance.

This activity will address Question 9.3 of the CCSP Strategic Plan, and will support Decision-Support Objectives 1.1 and 3.2.

DECISION-SUPPORT RESOURCES DEVELOPMENT CHAPTER REFERENCES

1) See <uaf.edu/accap>.
2) **Rosen**, R., A. Chu, J.J. Szykman, R. DeYoung, J.A. Al-Saadi, A. Kaduwela, and C. Bohnenkamp, 2006: Application of satellite data for three-dimensional monitoring of $PM_{2.5}$ formation and transport in San Joaquin Valley, California. In: *Remote Sensing of Aerosol and Chemical Gases, Model Simulation/Assimilation, and Applications to Air Quality* [Chu, A., J. Szykman, and S. Kondragunta (eds.)]. Proceedings of SPIE - International Society of Optical Engineering, **6299**, doi:10.1117/12.681649.
3) See <weather.gov/climate/l3mto.php>.
4) **Hadley**, S., D.J. Erickson III, J. Hernandez, C. Broniak, and T.J. Blasing, 2006: Responses of energy use to climate change: A climate modeling study. *Geophysical Research Letters,* **33**, L17701, doi:10.1029/2006GL026131.
5) See <climate.noaa.gov/cpo_pa/risa>.



8 Observing and Monitoring the Climate System

Observing and Monitoring the Climate System

Goal 12.1: Design, develop, deploy, and integrate observation components into a comprehensive system.
Goal 12.2: Accelerate the development and deployment of observing and monitoring elements needed for decision support.
Goal 12.3: Provide stewardship of the observing system.
Goal 12.4: Integrate modeling activities with the observing system.
Goal 12.5: Foster international cooperation to develop a complete global observing system.
Goal 12.6: Manage the observing system with an effective interagency structure.

Data Management and Information

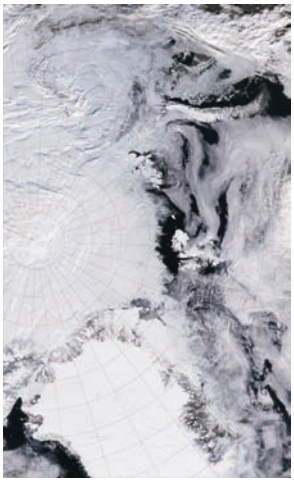
Goal 13.1: Collect and manage data in multiple locations.
Goal 13.2: Enable users to discover and access data and information via the Internet.
Goal 13.3: Develop integrated information data products for scientists and decisionmakers.
Goal 13.4: Preserve data and information.

See Chapters 12 and 13 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these goals.

Two overarching questions are identified in the *CCSP Strategic Plan* for "Observing and Monitoring the Climate System" (Chapter 12) and "Data Management and Information" (Chapter 13):

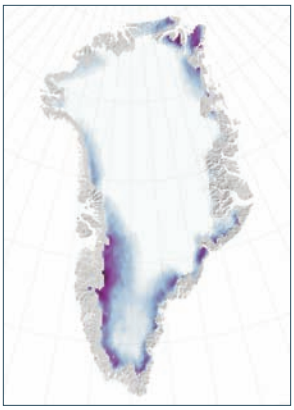
- How can we provide active stewardship for an observation system that will document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society?
- How can we provide seamless, platform-independent, timely, and open access to integrated data, products, information, and tools with sufficient accuracy and precision to address climate and associated global changes?

Long-term, high-quality observations of the global environment are essential for defining the current state of the Earth's system, its history, and its variability. This task requires both space- and surface-based observation systems. The term "climate observations" can encompass a broad range of environmental observations, including: (1) routine weather observations, which are collected consistently over a long period of time; (2) observations collected as part of research investigations to elucidate processes to maintain climate patterns or their variability; (3) highly precise, continuous observations of climate system variables collected for the express purpose of documenting long-term (decadal to centennial) change; and (4) observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time.



The United States contributes to the development and operation of several global observing systems, both research and operational, that collectively provide a comprehensive measure of climate system variability and climate change processes. These systems are a baseline Earth-observing system and include NASA, NOAA, and USGS Earth-observing satellites and extensive *in situ* observational capabilities. CCSP also supports several ground-based measurement activities that provide the data used in studies of the various climate processes necessary for better understanding of climate change. U.S. observational and monitoring activities contribute significantly to several international observing systems including the Global Climate Observing System (GCOS) principally sponsored by the World Meteorological Organization (WMO); the Global Ocean Observing System sponsored by the United Nations Educational, Scientific and Cultural Organization's Intergovernmental Oceanographic Commission (IOC); and the Global Terrestrial Observing System sponsored by the United Nations Food and Agriculture Organization. The latter two have climate-related elements being developed jointly with GCOS.

The importance of ongoing climate observations for detecting unusual changes over small time intervals has recently been emphasized for the Arctic. The Arctic region is experiencing unprecedented large and rapid changes. For example, the area and elevation of melting on the Greenland ice sheet have increased; glacier area, thickness, and volume in Alaska have decreased; permafrost temperatures have risen and thawing is occurring in many areas; Eurasian rivers' discharge into the Arctic Ocean has increased, and sea ice extent, thickness, and volume have decreased; and shrubs and "greenness" have increased on the North Slope of Alaska while boreal forest "greenness" has decreased and fires have increased due to drought. A specific subset of the GCOS observing activities for 2007 and 2008 are the CCSP-sponsored polar climate observations made in cooperation with the International Polar Year (IPY). IPY plans to advance polar observations by establishing a new level of multidisciplinary observatory using the latest technology in sensor web (i.e., a network of spatially distributed sensor platforms that

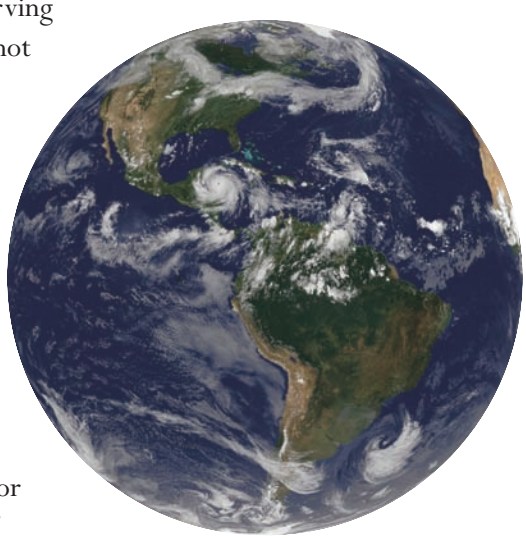


wirelessly communicate with each other) and power-efficient design. Data from these, and more traditional surface- and space-based observatories, will provide high-quality records needed to detect potential future climate change. The United States will increase its efforts on observations of the polar atmosphere, ice, and ocean, as well as leverage its investments in polar research with international partners.

Remotely sensed observations continue to be a cornerstone of CCSP. For example, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) lidar and CloudSat radar instruments are providing an unprecedented examination of the vertical structure of aerosols and clouds over the entire Earth. These data—when combined with data from the Aqua, Aura, and Parasol satellites orbiting in formation and called the "A-Train"— will enable systematic pursuit of key issues including the effects of aerosols on clouds and precipitation, the strength of cloud feedbacks, and the characteristics of difficult-to-observe polar clouds. With increases in data volume from a number of remote-sensing and *in situ* observing systems, a continuing challenge for CCSP agencies will be to ensure that data management systems are able to keep up with increases over the next several years. It is imperative that users can effectively make use of an increasing and diverse range of data products that include *in situ*, model output, and satellite data, which is expected to triple in volume by FY 2013.

Highlights of Recent Research

Selected highlights of observation and monitoring activities supported by CCSP-participating agencies follow. The principal focus of this chapter is on describing progress in implementing the observations that contribute to the CCSP mission. As a result, the chapter touches on some observing systems that are crucial to CCSP but are not included within the CCSP budget because they primarily serve other purposes.

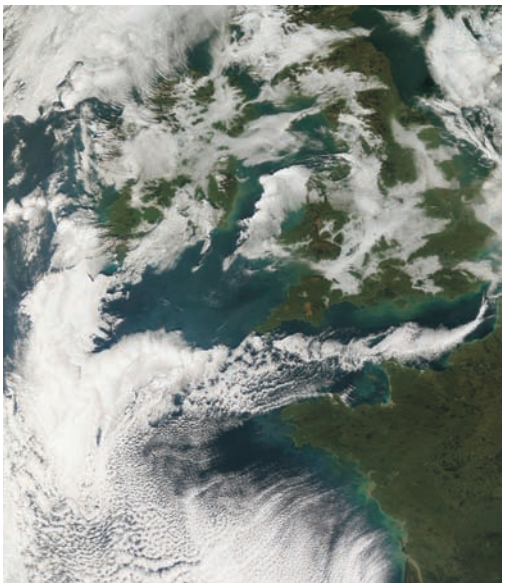


Observations and Monitoring

Tropical Moored Buoy Network Extended into the Indian Ocean. Working in close collaboration with Indian Ocean and Asian partners, a series of moored buoys have been deployed in the Indian Ocean for measurement of a comprehensive suite of

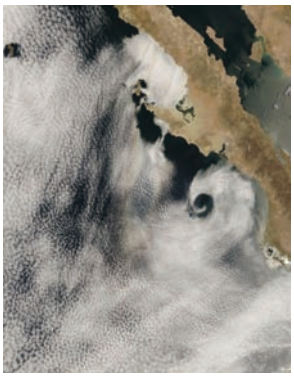
ocean-atmosphere climate variables. This westward extension of the equatorial Pacific Tropical Atmosphere Ocean/Triangle Trans-Ocean (TAO) array, whose long-term data have revolutionized understanding of the evolution of El Niño, is necessary to understand changes in Indian Ocean sea surface temperatures, which have recently been shown to influence regional climate variability and change (including prolonged drought in the mid-latitudes, including the United States). Since 2005, eight new TAO buoys were installed in the Indian Ocean in collaboration with partners from India, Indonesia, and France. Plans call for a total of 39 TAO buoys in the Indian Ocean by 2013.

Global Coverage Achieved by the Argo Profiling Array. Argo profiling floats, measuring upper ocean temperature and salinity, have now been deployed in all oceans. The United States operates approximately half of the global array in cooperation with 22 countries operating the other half. The floats drift at depth and periodically rise to the sea surface, collecting data along the way, and report their observations in real-time via satellite communications. This global data set is used together with complementary data from satellites and other *in situ* systems to document ocean heat content and global sea-level change.



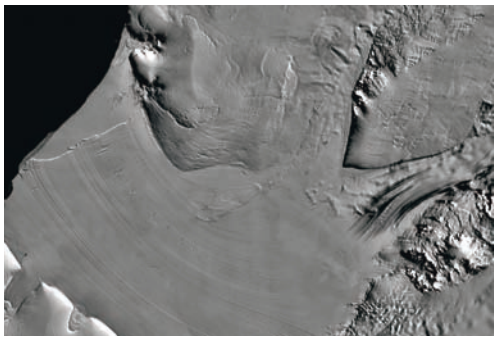
Satellite Observations of Atmosphere, Land, and Oceans. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument has been operating successfully on NASA's Earth Observing System (EOS) Terra mission for over 6 years and on the Aqua mission for over 4 years. The MODIS instruments have provided daily global observations of atmospheric, land, and ocean features with unprecedented detail, due to the 250- to 1,000-m spatial resolution coupled with multi-spectral capability in 36 carefully selected spectral bands extending from the visible to the thermal infrared portions of the electromagnetic spectrum. Observing the atmosphere, MODIS has produced advanced, detailed observations of the global and regional extent of aerosols from natural and anthropogenic activity. Analysis not only produces accurate determinations of the extent of cloudiness—including that associated with thin, wispy cirrus—that profoundly affects Earth's radiation balance, but also cloud properties such as cloud phase (water or ice), optical depth (i.e., cloud thickness), and effective droplet radius. The MODIS instruments are also providing more detailed observations of land features such as surface reflectance (albedo), surface temperature, snow and ice cover, and the variability of vegetation type and vigor associated with seasonal and climatic (e.g., above and below average moisture) variability. The capability of MODIS to classify vegetation types and the photosynthetic activity of vegetation over the land as well as in the surface waters

of the world's oceans (i.e., phytoplankton) is leading to more accurate evaluation of spatial and seasonal changes in the global net productivity of Earth's biosphere. The capability of MODIS to observe global processes and trends is leading to better understanding of natural and anthropogenic effects on the Earth-atmosphere system, and to better performance of general circulation models (GCMs). An example of the latter is the use of atmospheric winds derived from MODIS observations over the polar regions of the globe. These observations have been shown to improve the global predictive skill of several GCMs, both in the polar regions that are undergoing rapid change, and in the mid-latitudes.



Climate Sensitivity, Cloud Feedback, and Global Albedo.[1,2] Recent analyses of state-of-the-art climate model simulations show that uncertainties in cloud feedback continue to dominate uncertainties in climate sensitivity. These studies have also shown that cloud feedback is linearly proportional to changes in cloud radiative forcing, and that low cloudiness appears to dominate the cloud feedback uncertainty. The combination of studies suggests that changes in Earth's albedo through changing low-altitude cloudiness are one of the most critical observations. Analysis of global albedo using broadband satellite observations made from the Clouds and the Earth's Radiant Energy System (CERES) instrument showed that the interannual variations in global albedo are dominated by changes in the tropics. Examination of the year-to-year variability of tropical and global cloud properties observed by CERES and MODIS identified the need for a highly accurate satellite data set of 20 years or more to achieve a sufficient signal-to-noise ratio to estimate decadal changes in cloud radiative forcing representative of cloud feedback in the climate system. These studies have highlighted the increased capability of simultaneous measurements of a wide range of climate variables to allow the clarification of key relationships in major portions of the climate system.

QuikSCAT.[3,4] The SeaWinds instrument aboard the Quick Scatterometer (QuikSCAT) satellite has measured the speed and direction of wind over the surface of the oceans since 1999. Although launched as an experimental instrument, it has been assimilated pre-operationally into atmospheric weather prediction models (NOAA's National Centers for Environmental Prediction, the European Centre for Medium-Range Weather Forecasts, and others) for the past 2 years. It is providing new insights on air-sea exchanges. Furthermore, the underlying radar backscatter data have been applied to climate change research concerning terrestrial high latitudes through studies of ice layer formation.

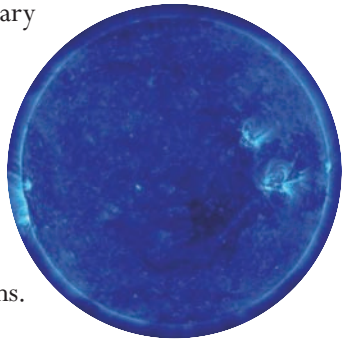


Clues to Variability in Arctic Minimum Sea Ice Extent.[5] Polar systems are especially sensitive to changing conditions and provide early indications of climate change. Perennial sea ice is a primary indicator of Arctic climate change. From 1979 to 2007, it decreased in extent by about 40%. Analysis of new satellite-derived fields of winds, radiative forcing, and transported heat energy reveals distinct regional differences in the relative roles of these parameters in explaining variability in the position of the northernmost ice edge. In all six peripheral seas studied, downwelling longwave radiation flux anomalies explain the most variability—approximately 40%—while northward wind anomalies are important in areas north of Siberia, particularly earlier in the melt season. Anomalies in the amount of solar energy absorbed by the surface are negatively correlated with perennial ice retreat in all regions, suggesting that the effect of solar flux anomalies is overwhelmed by the long-wave influence on ice edge position. This work has taken on new urgency with the 2007 Arctic sea ice minimum extent being the lowest in the 1978 to 2007 satellite record.

ICESat.[6] The Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003, has made significant contributions to CCSP's polar observations. The lidar instrument on ICESat measures surface elevations of ice and land, vertical distributions of clouds and aerosols, vegetation canopy heights, and other features with unprecedented accuracy and sensitivity. The primary purpose of ICESat has been to acquire time series of ice sheet elevation changes for determination of the present-day mass balance of the ice sheets, study of associations between observed ice changes and polar climate, and improvement of estimates of the present and future contributions to global sea-level rise. ICESat has achieved remarkable successes with first-of-their-kind observations:

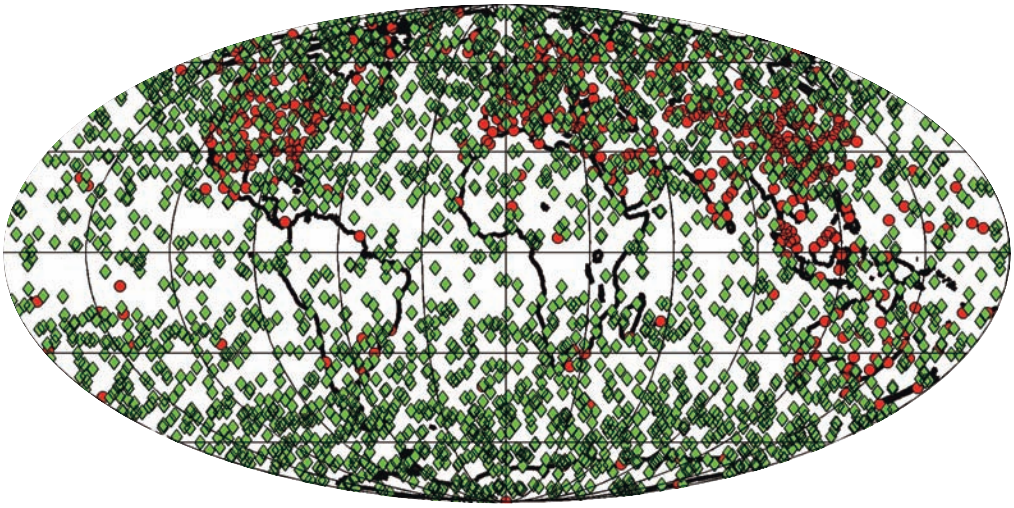
- The most accurate elevation maps to date of the Greenland and Antarctic Ice Sheets (centimeters per year)
- Detection of changes in the Greenland and Antarctic Ice Sheets
- Demonstrated ability to characterize detailed topographic features of ice sheets, ice shelves, and ice streams
- Pioneering sea ice thickness mapping (distributions and means).

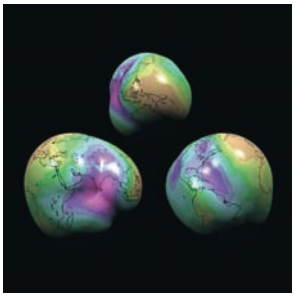
Solar Variability: SORCE Mission.[7] The Sun is the Earth's primary energy source and external driver of climate variability. The Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous instruments. SORCE is now making the first contiguous observations of solar variability across the full solar spectrum, from far ultraviolet to near-infrared wavelengths. SORCE's operational life extends across the 2006-2007 solar



minimum, a crucial period for estimating any long-term trend, such as that indicated by indirect measurements of past solar forcing. The mission is expected to overlap with the Glory mission that will carry forward the total solar irradiance record after 2008. The continued measurements previously planned by the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) through the Total Solar Irradiance Sensor (including a Total Solar Irradiance Monitor and Spectral Irradiance Monitor) were deleted from the NPOESS program during the Nunn-McCurdy recertification process completed in June 2006. Agencies are currently assessing the impacts of this decision for solar irradiance monitoring.

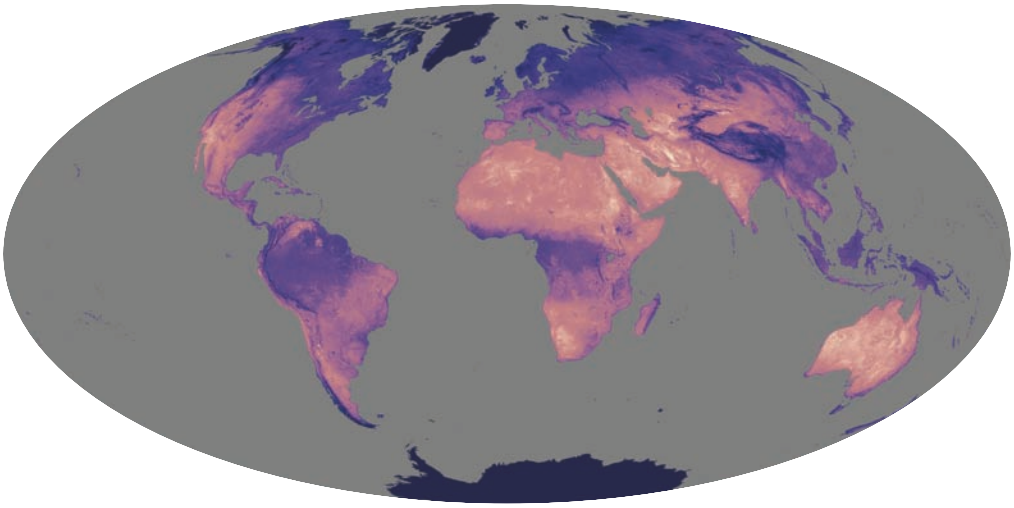
High-Resolution Vertical Profiles of Atmospheric Temperature and Moisture.[8] The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) relies on radio occultation of signals from the Global Positioning System satellites. COSMIC satellites take 2,500 vertical profile measurements every 24 hours in a nearly uniform distribution around the globe, filling in current data gaps over vast stretches of the oceans. The data's high vertical resolution complements the high horizontal resolution of other conventional weather satellite measurements. This is the first time that the technique of radio occultation has been used on a global scale and in real-time to provide continuous monitoring of worldwide atmospheric conditions. COSMIC builds on a series of previous research-oriented satellites, which were used to develop the measurement technique and establish the usefulness of the data in operational forecast systems. The remarkable stability, consistency, and accuracy of the measurements are a new precision tool to help scientists in quantifying long-term climate change trends. COSMIC was successfully launched on 14 April 2006, and its constellation of six small satellites will be transmitting atmospheric data to Earth for the next 5 or more years.





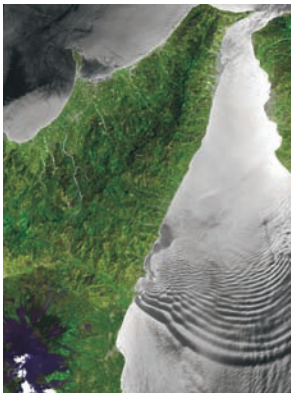
Observing Earth's Mass Distribution Changes from Space.[9] The Gravity Recovery and Climate Experiment (GRACE) is a two-spacecraft mission, developed under a partnership between NASA and the German Aerospace Center. After five successful years of mission operation, significant multidisciplinary results using GRACE observations have been reported. The unprecedented accuracy of the measurements provides the opportunity to observe time variability in the Earth's gravity field due to changes in mass distribution. The month-to-month gravity variations obtained from GRACE provide information about changes in the distribution of mass within the Earth and at its surface. The largest time-variable gravity signals are the result of changes in the distribution of water and snow stored on land. Analyses of these time variable gravity fields provide global observations of changes in total water storage (vertically integrated water content), averaged over scales of a few hundred kilometers and greater. Usefully accurate surface water storage estimates from GRACE allow quantitative comparisons to be made on seasonal and longer time scales. A recent study compared GRACE surface water storage estimates to the outputs of five models. All of the models reproduce the global annual pattern of storage amplitude and the seasonal cycle. However, global average agreements were found to mask systematic model biases at low latitudes. Identifying these errors in the models will allow improved parameterization of water stores in the land models and alleviate precipitation biases. Both processes are difficult to formulate and the satellite data will greatly aid in improving the veracity of the models.

Surface-Based Observatories of Clouds and Radiation.[10,11] The primary goal of the Atmospheric Radiation Measurement (ARM) program is to improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models. These efforts have been enhanced by the



addition of the ARM mobile facility (AMF) to study cloud and radiation processes in multiple climatic regimes. The AMF can be deployed to sites around the world for durations of 6 to 18 months. Data streams produced by the AMF will be available to the atmospheric community for use in testing and improving parameterizations in global climate models. The AMF was deployed in Niamey, Niger from January through December 2006 and measured radiation, cloud, and aerosol properties during the monsoon and dry seasons. Using measurements from the ARM Mixed-Phase Arctic Cloud Experiment (M-PACE), a data set has been created that allows climate and cloud models to simulate Arctic weather allowing for direct comparison of observations and model simulations.

Baseline Surface Radiation Network. The Baseline Surface Radiation Network has acquired 15 years of surface radiation budget data at its original half-dozen sites and has since expanded to more than 38 international sites. These observations combined with historic records have detected interdecadal annual mean variations on the order of about 2%, which exceeds previous expected variations that are not replicated in climate models. Contributing effects from clouds and aerosols are suspected to be the most likely cause of these variations.



Data Management and Information

Selected data management and information activities supported by CCSP-participating agencies follow.

REASoN Program.[12] Forty Cooperative Agreement projects that are part of NASA's Earth Science Research, Education, and Applications Solutions Network (REASoN) have completed their first year. The REASoN projects are part of NASA's strategy to work with its partners to improve its existing data systems, guide the development and management of future data systems, and focus performance outcomes to further Earth science research objectives. In order to achieve these goals, the REASoN projects are organized to engage the science community and peer review process in the development of higher level science products; to use these products to advance Earth system research; to develop and demonstrate new technologies for data management and distribution; and to contribute to interagency efforts to improve the maintenance and accessibility of data and information systems.

Global Change Master Directory.[13] The Global Change Master Directory (GCMD) is an extensive directory of descriptive and spatial information about data sets relevant to global change research. The GCMD provides a comprehensive resource where a

researcher, student, or interested individual can access sources of Earth science data and related tools and services. At present the GCMD database contains over 18,200 metadata descriptions of data sets from approximately 2,800 government agencies, research institutions, archives, and universities worldwide; updates are made at the rate of 900 descriptions per month. GCMD contains descriptions of data sets covering all disciplines that produce and use data to help understand our changing planet. Although much research is focused on climate change, the GCMD includes metadata from disciplines including atmospheric science, oceanography, ecology, geology, hydrology, and human dimensions of climate change. This interdisciplinary approach is aimed at researchers exploring the interconnections and interrelations of multidisciplinary global change variables (e.g., how climate change may affect human health). The GCMD has made it easier for such data users to locate the information desired. The latest version of the GCMD software was released in May 2007 as MD9.7. Software upgrades are made in response to user needs and to capitalize on new technology. A portal has been created in support of the Global Earth Observation System of Systems (GEOSS).

Highlights of Plans for FY 2008

CCSP will continue to develop and implement integrated systems for observing and monitoring global change, and the associated data management and information systems. Selected key planned activities for FY 2008 and beyond follow.

Global Climate and Ocean Observing Systems. FY 2008 priorities for advancement of the atmospheric and ocean observing components of GCOS include: (1) reducing the uncertainty in the carbon inventory of the global ocean, sea-level change, and sea surface temperature; (2) continuing support for existing *in situ* atmospheric networks in developing nations; and (3) planning for surface and upper air GCOS reference observations consistent with CCSP Synthesis and Assessment Report 1.1. As such, the global ocean observing system will make incremental advances, building out to 59% completion. In addition to the Argo array reaching global coverage, the TAO array in

the Pacific will begin to be refreshed with redesigned mooring technologies, and the TAO tropical system will be expanded further in the Indian Ocean. Three new ocean reference stations will be added to the system, for improved forecasts and modeling validation, assessments of climate impacts on ecosystems, and monitoring for possible rapid climate change. The tide gauge network will continue to be upgraded for real-time reporting, also contributing to the international tsunami warning system. Continued support will be given to the activities, database development, and data delivery systems of the international Global Sea-Level Observing System. The drifting arrays will be augmented with salinity sensors to better capture sea surface salinity and to provide calibration for the planned Aquarius satellite mission; and additional carbon dioxide (CO_2) sensors will be added to moored arrays and ships to analyze seasonal variability and exchange of CO_2 between the ocean and atmosphere. Work is underway on developing biological sensors as part of Ocean Observing Systems. Finally, planning activities will continue on developing a GCOS Reference Upper Air Network (GRUAN) to aid in enhancing the quality of upper tropospheric and lower stratospheric water vapor measurements at a subset of present GRUAN.

These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.

Polar Region Observations: International Polar Year. Polar climate observations will continue to be a CCSP focus in FY 2008. As a part of IPY, CCSP research will investigate the possible connections between Arctic haze aerosols and the melting of polar ice in the region. The investigation will involve multiple agencies in cooperation with scientists and facilities from several other countries. In addition to a wide variety of surface measurements, *in situ* and remote-sensing measurements will be made from balloons and aircraft. Satellite observations will include CALIPSO and Cloudsat, using lidar and radar instruments to provide three-dimensional distributions of aerosols and layered clouds. Surface field teams from many nations will be supported by a wealth of satellites contributed for polar research by multiple space agencies.

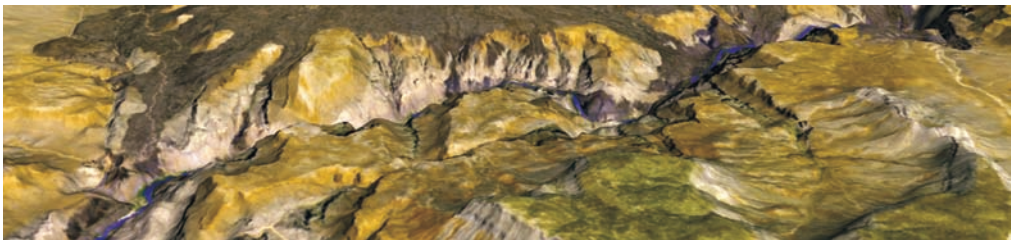
These activities will address Goals 12.1 and 12.5 and Questions 3.1 and 3.3 of the CCSP Strategic Plan.

In Situ Observations: International Polar Year. The Arctic Observing Network (AON) is envisioned as a system of atmospheric, land- and ocean-based environmental monitoring capabilities—from ocean buoys to satellites—that will significantly advance observations of Arctic environmental conditions. Developed largely as a research system under the leadership of NSF and NOAA, it is hoped that data from AON will eventually enable the interagency U.S. government initiative—the Study of Environmental Arctic Change—to better understand the wide-ranging series of significant and rapid changes

occurring in the Arctic. From April to July 2008, the United States will conduct aircraft flights over the North Slope of Alaska to measure temperature, humidity, total particle number, aerosol size distribution, cloud condensation nuclei concentration, ice nuclei concentration, optical scattering and absorption, vertical velocity, cloud liquid water and ice contents, cloud droplet and crystal size distributions, cloud particle shape, and cloud extinction. These data, coupled with ground-based measurements, will be used to evaluate model simulations of Arctic climate. The new NASA CALIPSO Lidar and CloudSat radar are providing an unprecedented examination of the vertical structure of aerosols and clouds over the entire Earth. These data—when combined with data from the A-train configuration of the Aqua, Aura, and Parasol satellites orbiting in formation—will enable systematic observation of the key climate forcing of aerosol indirect effects, climate sensitivity of cloud feedbacks, and polar climate response of difficult-to-observe polar clouds. The last of these capabilities will also directly support IPY activities. Finally, a U.S. Climate Reference Network system will be deployed at the Russian Arctic site of Tiksi at latitude 71.5°N in order to provide long-term reference measurements of temperature, precipitation, wind, pressure, and surface radiation in support of IPY and beyond.

These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.

Data Fusion. As the length of record in the database of global observations increases, increased effort will be placed on assimilating Earth observations into GCMs, to produce an integrated view of the climate system and to better provide this view to users as part of decision-support and resource management systems. The value of the data itself will benefit by increased "data fusion" in which, for example, MODIS observations will be joined with the complementary capabilities of other Earth-observing instruments, to provide much improved, more accurate and rigorous observations of key phenomena such as sea surface temperature, cloud characteristics, and land surface features. Data fusion efforts will include instruments on existing EOS missions such as Terra, Aqua, ICESat, Aura, Landsat, and SORCE, and on recently launched missions such as CloudSat and CALIPSO and, farther in the future, Earth System Science Pathfinder missions and the Global Precipitation Measurement (GPM) Mission. The fusion of space-borne observations with *in situ* biological and physical observations, such as those gathered through the National Ecological Observatory



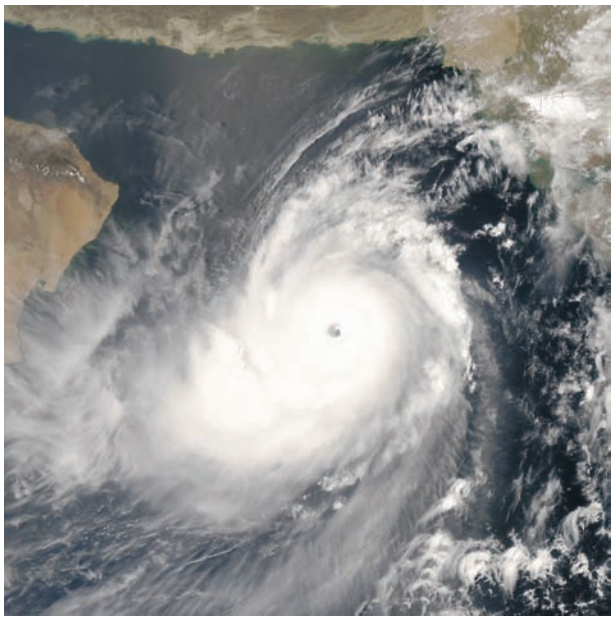
Network and the Ocean Observing Initiative, is crucial for gaining a better understanding of trends and associated consequences of the variability in the atmosphere-land-ocean system. This activity is closely related to the CCSP Climate Variability and Change research element's priority of improving Earth system analysis capabilities.

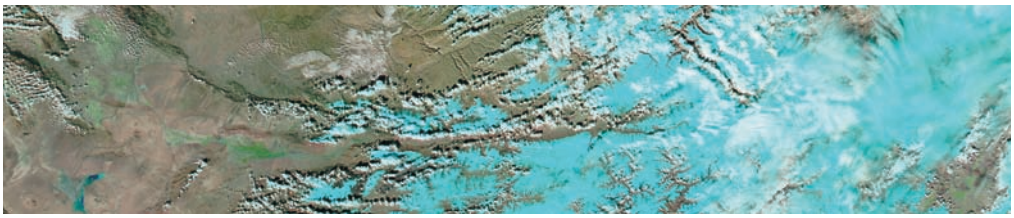
These activities will address Goals 13.2 and 13.3 of the CCSP Strategic Plan.

Solar Variability: Glory.[14] The Glory mission will continue to be developed in FY 2008, and is planned to launch in 2009. It will carry a Total Irradiance Monitor (TIM) based on the SORCE TIM design, with the same high-precision phase-sensitive detection capability. Glory will also carry an Aerosol Polarimeter Sensor (APS), which will improve ability to distinguish among aerosol types by measuring the polarization state of reflected sunlight. Both TIM and APS will provide key measurements of the minimum of solar cycle 24. This less-active portion of the 11-year solar cycle is especially crucial in estimating any long-term trends in solar output—a key to understanding the 20th-century context of global change, as the Sun is the single entirely "external" forcing of the climate system that is unaffected by climate change itself.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Global Precipitation Measurement Mission. Motivated by the successes of the Tropical Rainfall Measuring Mission (TRMM) satellite and recognizing the need for a more comprehensive global precipitation measuring program, NASA and the Japan Aerospace Exploration Agency conceived a new Global Precipitation Measurement (GPM) Mission. A fundamental scientific goal of the GPM Mission is to make substantial improvements in global precipitation observations, especially in terms of measurement accuracy, sampling frequency, spatial resolution, and coverage—thus extending TRMM's rainfall time series. To achieve this goal, the mission will consist of a constellation of low-Earth-orbiting satellites carrying various passive and active microwave measuring instruments. The record of precipitation has been extended in recent years to include oceanic as well as land areas using satellite measurements from TRMM. This is an example





of a key climate data set to be maintained and extended into the future. The GPM Mission will be used to address important issues central to improving the predictions of climate, weather, and hydrometeorological processes, to stimulate operational forecasting, and to underwrite an effective public outreach and education program, including near-real-time dissemination of televised regional and global rainfall maps.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Aquarius. Aquarius is a satellite mission to measure global sea surface salinity. The average ocean salinity is about 35 parts per 1,000. The instruments that are part of this satellite mission will measure changes in sea surface salinity over the global oceans to a precision of 0.2 parts per 1,000 (equivalent to about 1/6 of a teaspoon of salt in 1 gallon of water). By measuring global sea surface salinity with good spatial and temporal resolution, Aquarius will answer long-standing questions about how oceans respond to climate change and the water cycle, including changes in freshwater input and output to the ocean associated with precipitation, evaporation, ice melting, and river runoff. Aquarius is a collaboration between NASA and CONAE, the Argentine space agency, with an expected launch date in 2010.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Ocean Surface Topography Mission. The accurate, climate-quality record of sea surface topography measurements—started in 1992 with TOPEX/POSEIDON and continued in 2001 by the Jason satellite mission—will be extended with the Ocean Surface Topography Mission (OSTM). These missions have provided accurate estimates of regional sea-level change and of global sea-level rise. Ocean topography measurements from these missions have elucidated the role of tides in ocean mixing and maintaining deep ocean circulation. Furthermore, quantitative determination of ocean heat storage from satellite measurements together with measurements from the global array of temperature/salinity profiling floats known as Argo have confirmed climate model predictions of the Earth's energy imbalance that is primarily due to greenhouse gas forcing. The high levels of absolute accuracy and cross calibration make these missions uniquely suited for climate research. OSTM is a collaboration among NASA, NOAA, the French space agency CNES, and the European meteorological agency EUMETSAT, and has a planned 2008 launch.

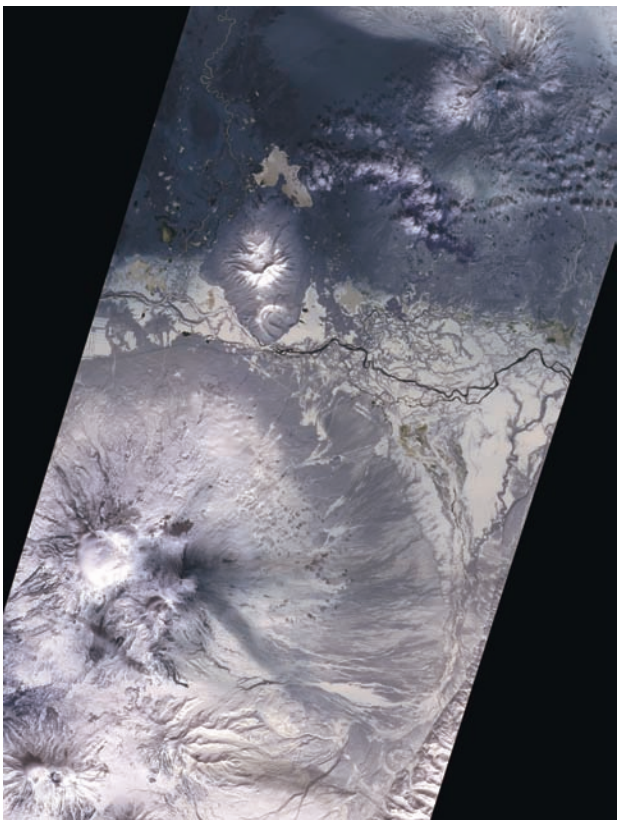
These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Orbiting Carbon Observatory. The Orbiting Carbon Observatory (OCO) is a new mission, expected to launch in 2008, that will provide the first dedicated, space-based measurements of atmospheric CO_2 (total column) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability. Analyses of OCO data will regularly produce precise global maps of CO_2 in the Earth's atmosphere that will enable more reliable projections of future changes in the abundance and distribution of atmospheric CO_2 and studies of the effect that these changes may have on the Earth's climate.

These activities will address Goals 12.2 and 12.5 of the CCSP Strategic Plan.

Continuity of Climate Measurements.[15,16] As new satellite instruments bring new measurement capabilities, the challenge becomes establishing priorities for the right mix of existing observing capabilities and new capabilities to support the goals of CCSP. Continuity of measurement of several key climate variables are being carefully considered including stratospheric ozone, radiative energy fluxes of the Sun and Earth, atmospheric CO_2 and methane concentrations, global surface temperature, and global land cover (e.g., as measured by Landsat).

The long-term record of global land cover was begun by Landsat 1 in 1972 and continues through the collection of data from Landsats 5 and 7. Launched in 1984, with a design life of 3 years, Landsat 5 continues to provide near-global coverage through a network of international ground station cooperators. Landsat 7 was launched in 1999, and continues to acquire global observations on a daily basis although in a degraded operating mode. The combined assets of Landsats 5 and 7 permit repeat coverage as frequently as every eight days over ground-receiving station sites. Efforts to create a long-term record of global land cover, started by Landsat in the 1970s, are currently being prepared for the transition to a Landsat Data Continuity Mission (LDCM)



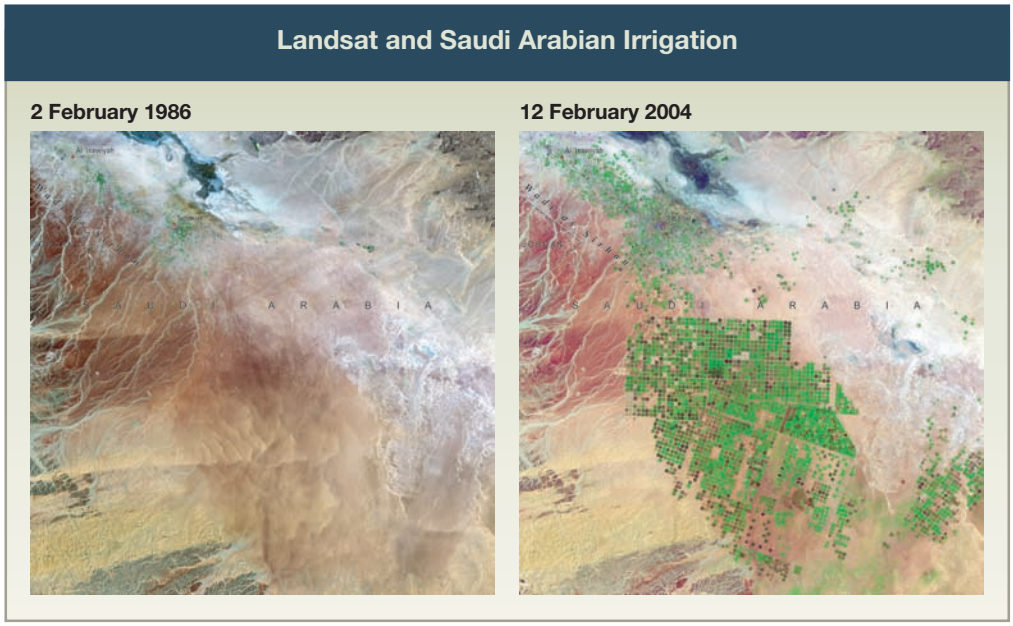


Figure 14: Landsat and Saudi Arabian Irrigation. Landsat images, from 1986 and 2004, reveal the effects of center-pivot irrigation in a desert region in Saudi Arabia known as Wadi As-Sirhan. In the satellite images, these irrigated fields appear as green dots. This region was once so barren that it could barely support the towns Al'Isawiyah and Tubarjal shown in the upper left of each image. Following the introduction of center-pivot irrigation, the barren desert was gradually transformed into a greener, food-producing landscape. The irrigation system draws water from an ancient underground aquifer. *Credit: USGS / EROS Data Center.*

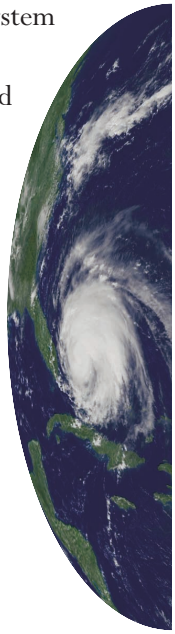
being planned by NASA and USGS. LDCM is expected to have a 5-year mission life with 10-year expendable provisions. The National Land Imaging Program Plan provides long-term planning for a stable, operational, space-based land imaging capability. See Figure 14 for an example of the usefulness of the Landsat data record.

Planning continues on deploying component sensors from NPOESS. A decision was made in June 2006 to delete many of the climate related instruments from NPOESS. These sensors included those for earth radiation budget, solar irradiance (total and spectrally resolved), high-resolution ozone vertical profile, aerosol optical properties, and sea surface topography. Agencies are currently assessing the impacts of this decision and evaluating options. The NPOESS Preparatory Project is scheduled as a bridge mission between NASA's EOS program in 2009, and NPOESS, now scheduled for its first launch in 2013.

The record of precipitation that has been extended in recent years to include oceanic as well as land areas using measurements from TRMM is another example of a key climate data set that needs to be considered as priorities are set for the future. These examples of key climate variables are elements of the comprehensive observing system to monitor changes in the cycles of carbon, energy, water, and related biogeochemical processes that drive Earth's climate.

These activities will address Goals 12.3 and 12.6 of the CCSP Strategic Plan.

Integrated Ocean Observing System.[17] The Integrated Ocean Observing System (IOOS) is the U.S. coastal-observing component of the Global Ocean Observing System (GOOS) and is envisioned as a coordinated national and international network of observations, data management, and analyses that systematically acquires and disseminates data and information on past, present, and future states of the oceans. A coordinated IOOS effort is being established by NOAA via a national IOOS Program Office co-located with the <Ocean.US> consortium of offices consisting of NASA, NSF, NOAA, and the Navy. The IOOS observing subsystem employs both remote and *in situ* sensing. Remote sensing includes satellite-, aircraft-, and land-based sensors, power sources, and transmitters. *In situ* sensing includes platforms (ships, buoys, gliders, etc.), *in situ* sensors, power sources, sampling devices, laboratory-based measurements, and transmitters.



These activities will address Goals 12.1, 12.3, and 12.6 of the CCSP Strategic Plan.

OBSERVING AND MONITORING THE CLIMATE SYSTEM CHAPTER REFERENCES

1) **Bony**, S. and J.L. Dufresne, 2005: Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models. *Geophysical Research Letters*, **32**, L20806, doi:10.1029/2005GL023851.
2) **Soden**, B.J. and I.M. Held, 2006: An assessment of climate feedbacks in coupled ocean-atmosphere models. *Journal of Climate*, **19**, 3354-3360.
3) **Chelton**, D.B., M.G. Schlax, M.H. Freilich, and R.F. Milliff, 2004: Satellite measurements reveal persistent small-scale features in ocean winds. *Science*, **303**, 978-983.
4) **Nghiem**, S.V., K. Steffen, G. Neumann, and R. Huff, 2005: Mapping of ice layer extent and snow accumulation in the percolation zone of the Greenland ice sheet. *Journal of Geophysical Research*, **110**, F02017, doi:10.1029/2004JF000234.
5) **Parkinson**, C.L. and D.J. Cavalieri, 2007: Arctic sea ice extents, areas, and trends, 1979-2006. *Journal of Geophysical Research – Oceans* (accepted).
6) See <icesat.gsfc.nasa.gov>.
7) See <lasp.colorado.edu/sorce>.
8) See <www.cosmic.ucar.edu/about.html>.
9) **Swenson**, S.C. and P.C.D. Milly, 2006: Climate model biases in seasonality of continental water storage revealed by satellite gravimetry. *Water Resources Research*, **42**, W03201, doi:10.1029/2005WR004628.
10) See <www.arm.gov/sites/amf.stm>.
11) **Xie**, S., S.A. Klein, M. Zhang, J.J. Yio, R.T. Cederwall, and R. McCoy, 2006: Developing large-scale forcing data for single-column models and cloud-resolving models from the Mixed-Phase Arctic Cloud Experiment. *Journal of Geophysical Research*, **111**, D19104, doi:10.1029/2005JD006950.
12) A list of ongoing activities under this program is available at <research.hq.nasa.gov/code_y/nra/current/CAN-02-OES-01/winners.html>.
13) See <globalchange.nasa.gov> or <gcmd.nasa.gov>.
14) See <glory.giss.nasa.gov>.
15) **Hansen**, J., L. Nazarenko, R. Ruedy, M. Sato, J. Wiollis, A. Del Genio, D. Koch, A. Lacis, K. Lo, S. Menon, T. Novakov, J. Perlwitz, G. Russell, G.A. Schmidt, and N. Tausnev, 2005: Earth's energy imbalance: Confirmation and implications. *Science*, **308**, 1431-1435.
16) **NSTC**, 2007: *A Plan for a U. S. National Land Imaging Program.* Future of Land Imaging Interagency Working Group, Washington, DC, 84 pp. Available at <www.ostp.gov/html/FLI-IWG%20report%20Print-ready%20low-res.pdf>.
17) See <www.ocean.us>.

9 Communications

CCSP, in its vision for the program, identified communications as one of four core approaches for achieving its five overarching scientific goals. CCSP is committed to communicating with interested partners in the United States and throughout the world, and to learning from these partners on a continuing basis. As an essential part of its mission, CCSP stresses openness and transparency in its findings and reports.

The Communications Interagency Working Group (CIWG), established during FY 2004, develops and executes an implementation plan each year that focuses on disseminating the results of CCSP activities credibly and effectively, and making CCSP science findings and products easily available to a diverse set of audiences. Elements of the implementation plan for calendar year 2007 include:

- *Media Relations.* When requested by the CCSP Director, assist in communicating on climate science issues.
- *Public Outreach.* Develop materials and methods for public outreach on issues related to climate science and the activities and products of CCSP.
- *Web Sites.* Develop and advance a strategy for improving, integrating, and promoting the content of web sites operated or supported by CCSP and its participating agencies, recognizing that the sites are essential communication and outreach tools.

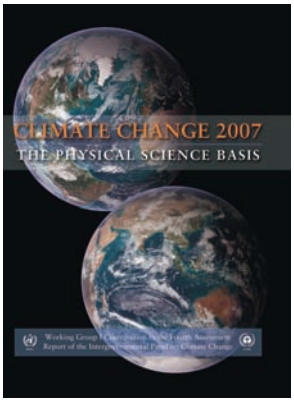
The Climate Change Science Program Office (CCSPO), funded and supervised by the agencies and departments participating in CCSP, supports the program's communications goals, along with members of the CIWG. CCSPO assists the CIWG, coordinates preparation of the annual *Our Changing Planet* report to Congress as well as other reports, and is responsible for managing the program's interagency web sites.

Highlights of Recent Interagency Communications Activity

Listed below are highlights of recent communication activities coordinated at the interagency level:

- Published and distributed (in both hardcopy and online) the FY 2007 edition of *Our Changing Planet*, the program's annual report to Congress and the President.

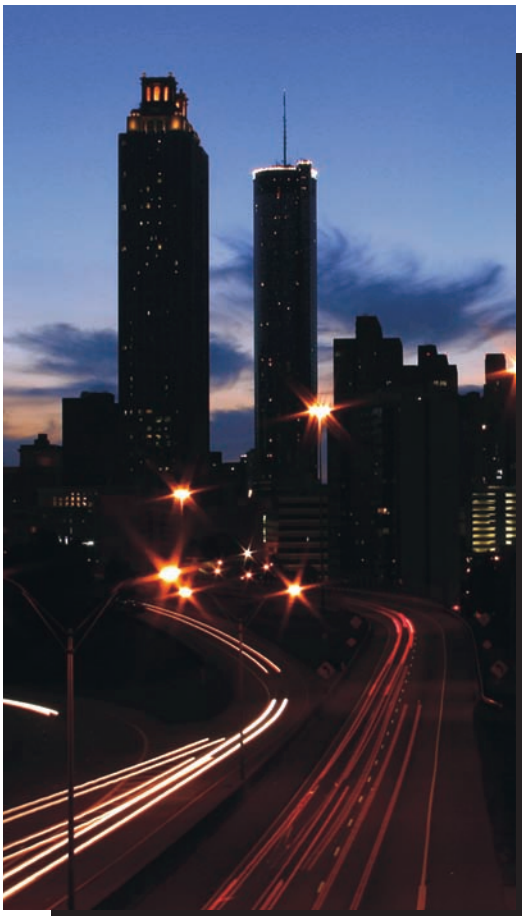
- Produced and distributed Synthesis and Assessment Product (SAP) 2.1, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application*. Release included a series of briefings and other activities focused on communicating the report findings.
- Posted online drafts of SAP prospectuses and reports for public comment. The prospectuses provide background information on each planned report and a detailed roadmap used in producing it. All submitted public comments also were posted, along with the authors' responses.
- Posted peer review comments on draft SAP reports, along with the authors' responses.
- Facilitated stakeholder participation in the U.S. Government review of draft documents of the Intergovernmental Panel on Climate Change (IPCC).
- Distributed hardcopies of the Summary for Policymakers of the Working Group contributions to the Fourth Assessment Report of the IPCC.
- Managed and improved CCSP web sites. Traffic to CCSP's three main sites increased to over 16,700 visits per day by May 2007, a 36% increase over May 2006. CCSPO also improved web services to facilitate interagency collaboration.
- Managed the Global Change Research Information Office (GCRIO), mandated by the Global Change Research Act of 1990. GCRIO includes a major web site with an online catalog for requesting reports and CDs. Through the catalog, GCRIO distributes an average of 700 items each month.
- Managed the Climate Change Technology Program (CCTP) public web site, where the number of visits by May 2007 was up 43% from a year prior. The *CCTP Strategic Plan* is among the major recent postings. CCSPO also provides additional support services to CCTP, including development and management of password-protected web sites and publications support.



Highlights of Plans for FY 2008

Listed below are some of the communications activities coordinated at the interagency level and planned for FY 2008:

- Post on the CCSP web site drafts of SAP reports for public review and comment. All submitted comments will be posted along with the authors' responses.
- Post peer review comments on draft SAP reports, along with the authors' responses.
- Produce and distribute final SAP reports. CIWG will advise the SAP teams and lead agencies on communications-related issues, including: dissemination to appropriate stakeholders; briefings; press releases; and summaries for a range of audiences across different information media.
- Prepare, publish, publicize, and disseminate the FY 2008 and FY 2009 editions of *Our Changing Planet*.
- Continue to improve and expand web sites by preparing and posting new web content, improving web site usability and accessibility, enhancing integration between agency and interagency web sites, and expanding web services to CCSP working groups.



10 International Research and Cooperation

The United States—through CCSP, individual agency, and multi-agency efforts—participates in and supports a wide range of international cooperative activities related to global change and climate change research. These activities include support of key international climate change science research programs, especially those under the aegis of the International Council for Science (ICSU), and their regular review; support of ongoing international assessments; support of regional global change research networks; participation in informal organizations that foster global change research; and support of international efforts aimed at improving and coordinating observations of the Earth.

These enable U.S. scientists acting in cooperation with their colleagues in other countries across the globe to aggregate the critical mass of scientific and financial resources necessary to conduct well-directed comprehensive studies of Earth system processes and their variability and change on both regional and global scales; to provide guidance to CCSP and its participating agencies; to suggest balance to our national research efforts; and, in many cases, to facilitate the exchange of scientists, facilities, and data needed for climate change research.

Individually, CCSP-participating agencies support international activities that correspond with specific agency goals or missions, and/or for which they have been given the lead for the Federal government. In the latter case, and where appropriate, CCSP also provides a centralized structure for soliciting, communicating, coordinating, compiling, and transmitting U.S. input to a variety to international organizations addressing climate and global change research issues of importance to the United States. This includes support to the Department of State regarding programs of the United Nations specialized agencies involved in climate and global change research, the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), and bilateral arrangements for cooperation in climate change science and technology.

CCSP provides appropriate U.S. shares of multilateral funding for centralized coordination of international research programs that are critically important to

international cooperation. This centralized coordination of these programs allows the international programs to collaborate with national research networks on disciplinary and interdisciplinary scientific endeavors and allows for the coordination of important synthesis reports. CCSP, through distributed costs, supports the activities of the IPCC's Working Group I Technical Support Unit and the partner programs of the Earth System Science Partnership (ESSP) including the SysTem for Analysis, Research and Training (START). Long-term and active participation in and contributions to regional research networks including the Inter-American Institute for Global Change Research (IAI), the Asia Pacific Network for Global Change Research (APN), and the burgeoning African cooperation in global change research fosters global change research in developing countries, develops research-driven capacity in those countries, and fosters research partnerships that ultimately support global goals in research into and observations of the Earth system.

The United States, through CCSP, also actively participates in and regularly contributes to a variety of informal activities that are dedicated to coordinating and fostering national global change research programs. Through these informal partnerships, such as the International Group of Funding Agencies for Global Change Research (IGFA), CCSP has an opportunity to interact informally with their counterpart national funding agencies with lead responsibilities for funding of climate and global change research in their countries and regions. IGFA also provides a forum through which ICSU and international global change research programs can interact and exchange information and views on the current state of global change research funding, future directions in global change research, important changes in national and regional programs, and a host of other issues.

The United States, through CCSP, also participates in a variety of programs that promote cooperation with other countries, directly enhance research capabilities in developing countries, and enhance climate forecasting and thereby adaptive capacity to respond to climate change in developing countries.

Updates of key international activities and CCSP interaction with and support of these activities follow. For more detailed information, see Chapter 15 of the *Strategic Plan for the U.S. Climate Change Science Program*.

Highlights of Recent Activities

Intergovernmental Panel on Climate Change Fourth Assessment Report. The IPCC began release of its Fourth Assessment Report (AR4) in early 2007. In addition to providing scientific expertise and leadership during the drafting and editing process, CCSP supports the activities of the Working Group I Technical Support Unit via interagency distributed costs. Via its coordination office, CCSP managed the U.S. author nomination process, the Expert and Government Reviews, and the final government review of the Summaries for Policymakers for Working Groups I and II. The Working Group I report, *Climate Change 2007: The Physical Science Basis*, was accepted in February 2007; the Working Group II report, *Climate Change 2007: Impacts, Adaptation, and Vulnerability*, in April 2007; and the Working Group III report, *Climate Change 2007: Mitigation of Climate Change*, in May 2007. The final Synthesis Report is scheduled for release in November 2007.

Famine Early Warning System Network Program. USAID Famine Early Warning System Network (FEWS NET) efforts to provide short- and long-term climate forecasting in the developing world is helping to enhance the adaptive capacity of developing countries to respond to climate variability and change. For instance, in August 2005, FEWS NET released a report on *Recent Drought Tendencies in Ethiopia and Equatorial Subtropical Eastern Africa*, which demonstrated how warming in the Indian Ocean and changes in the monsoonal circulation pattern could reduce rainfall across large areas of the Greater Horn of Africa. A new report is being prepared that extends this analysis to other areas of the African continent. This information will better enable development agencies and regional and local institutions to direct appropriate resources and support toward strengthening the adaptive capacity of affected groups and the food production systems upon which they depend.

World Climate Research Program. In addition to its extensive core activities, the World Climate Research Program (WCRP) in 2006 contributed significantly to the IPCC AR4 through the WCRP-Coupled Model Intercomparison Project. WCRP reported to the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA) 25 on research gaps and needs related to the convention with ESSP partners. WCRP also held a successful workshop on sea-level rise and variability which developed an interdisciplinary international consensus on observational needs for monitoring sea-level rise. WCRP, in cooperation with the International Geosphere-Biosphere Programme (IGBP), convened a workshop on next-generation

Earth system models and emissions scenario requirements in preparation for the IPCC Fifth Assessment Report (AR5) and communicated them to the IPCC Chair.

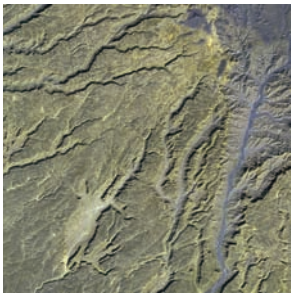
International Geosphere-Biosphere Programme. In addition to the successful input to the IPCC with the WCRP through the Coupled Carbon Cycle Model Intercomparison Project, IGBP published its second-phase Science Plan and Implementation Strategy that will guide the IGBP with nine core projects through the coming years. IGBP joined with CCSP and others to sponsor the first AfricaNess Workshop in 2005 and continued its support of development of an African Global Change Research Network. Currently, a science plan is under development to underpin the efforts of this network.

International Human Dimensions Programme. The International Human Dimensions Programme (IHDP) is currently preparing a science plan for the period 2007 to 2015. IHDP has also recently decided to relocate the activities of its central secretariat to the United Nations University in Bonn to reduce costs and improve the international linkages of its programs. Given its unique scientific community that includes social scientists who study the science policy and science practice interface, IHDP's increased emphasis on decision support complements the decision-support activities of CCSP.

DIVERSITAS Programme. DIVERSITAS emphasizes aspects of biodiversity science related to climate and global change, thus complementing CCSP's responsibility to monitor changes in biodiversity related to global change. In 2006, DIVERSITAS' international profile continued to expand. The program was recognized as a Participating Organization in the Group on Earth Observations GEO-III plenary and asked to serve as the lead agency for the Biodiversity Societal Benefit Area; and, with the Global Terrestrial Observing System, the Global Biodiversity Information Facility, and GEO organized a workshop to define user needs for a global biodiversity observing system. The program also continued to provide significant contributions to development of an International Mechanism of Scientific Expertise on Biodiversity (IMoSEB). DIVERSITAS continues to make progress in implementing all of its core projects including forging critical links with other programs' projects and activities.

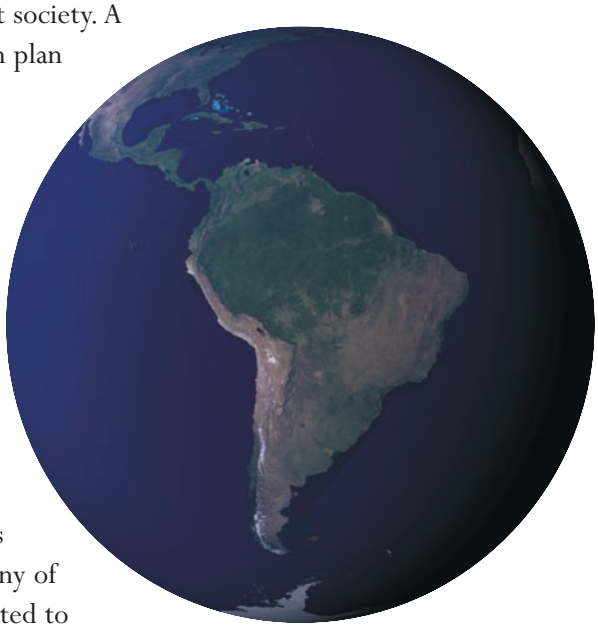
Earth System Science Partnership. The Earth System Science Partnership hosted its Second Open Science Conference on "Global Environmental Change: Regional Challenges" in November 2006 in Beijing, People's Republic of China. This meeting brought together over 800 scientists from virtually all climate and global change research disciplines. At this meeting, the Global Environmental Change and Human Health Project and the Monsoon Asia Integrated Regional Study (MAIRS) were launched. These projects, along with the Global Water System Project (GWSP), the

Global Carbon Project (GCP), and Global Environmental Change and Food Systems (GECAFS), are expected to contribute to significant scientific advances in the science of global change research.



SysTem for Analysis, Research and Training Programme. START programs, given their focus on development of research-driven capacity in developing countries for all of the ESSP programs, directly supports U.S. goals of fostering global change research and developing research capacity as called for in the Global Change Research Act of 1990. With its global reach and extensive on-the-ground experience working with scientific principal investigators, local communities, governments, and young scientists, the START program has played a critical role in advancing a variety of projects of interest to the United States and the global scientific community. Prior to the ESSP Open Science Conference, the START program successfully held its second START Young Scientists Conference which brought together the talent of early career scientists from all over the world (including many from the United States) and from many global change disciplines to discuss their research and forge connections that will promote international collaborative scientific cooperation and activities. START, through its connections with development aid agencies, is uniquely positioned to forge meaningful connections between the global change research and development communities.

Global Earth Observation System of Systems. The United States is playing an important role in the Global Earth Observation System of Systems (GEOSS), an international framework for coordinating and sustaining Earth observations and related information. Information from GEOSS is expected to revolutionize understanding of the Earth and how Earth observations may benefit society. A copy of the 10-year implementation plan for GEOSS adopted by the United States and nearly 60 countries in February 2005 may be found at <www.earthobservations.org>. The U.S. Group on Earth Observations (USGEO) has drafted a strategic plan for integrated Earth observations, which contributes directly to GEOSS. CCSP coordinates USGEO's climate and global change-related activities. USGEO is focusing on the following areas, many of which are directly or indirectly related to

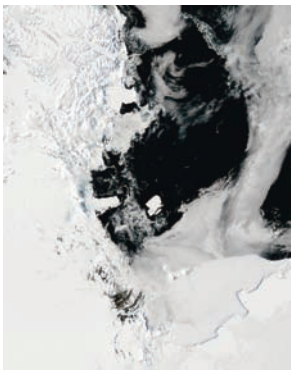


CCSP: understanding, assessing, predicting, mitigating, and adapting to climate variability and change; weather forecasting; reducing loss of life and property from disasters; protecting and monitoring ocean resources; supporting sustainable agriculture and combating land degradation; understanding the effect of environmental factors on human health and well-being; developing the capacity to make ecological forecasts; protecting and monitoring water resources; and monitoring and managing energy resources.

Bilateral Cooperation in Climate Change Science and Technology. Since June 2001, the United States has launched bilateral climate partnerships with 15 countries and regional organizations that, combined with the United States, account for almost 80% of global greenhouse gas emissions (for a more substantive discussion of the climate change science and technology bilaterals, see <www.climatescience.gov/Library/stratplan2003/final/ccspstratplan2003-chap15.htm#5>). Partnerships have been established with Australia, Brazil, Canada, China, Central America (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), the European Union, Germany, India, Italy, Japan, Mexico, New Zealand, the Republic of Korea, the Russian Federation, and South Africa. These bilateral initiatives seek to build on key elements of CCSP and the Climate Change Technology Program, including research, observations, data management and distribution, and capacity building.

Successful joint projects have been initiated in areas such as climate change science; clean and advanced energy technologies; carbon capture, storage, and sequestration; and policy approaches to reducing greenhouse gas emissions. The United States is also assisting key developing countries in efforts to build the scientific and technological capacity needed to address climate change.

Two ongoing objectives for the bilateral activities will be continued advancement of results-oriented programs and the fostering of substantive policy dialogs within all of the bilateral climate change partnerships. In order to broaden U.S. cooperative efforts to advance a practical and effective global response to climate change, the United States will expand outreach and support to the developing country community, utilizing a regional approach where feasible.



Highlights of Plans for FY 2008

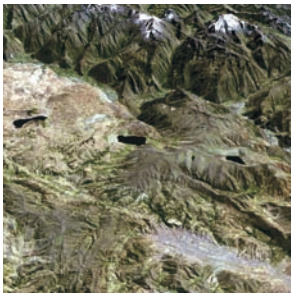
World Climate Research Program. WCRP will focus primarily on implementation of its 2005-2015 Strategic Framework while pursuing its multi-year activities and core projects. WCRP will also pursue a set of short-term cross-cutting activities to develop and coordinate research of immediate relevance to end users. In 2007, WCRP will focus on effective dialogue with UNFCCC/SBSTA, prioritizing research for the overall UNFCCC following on the IPCC AR4 and in preparation for the AR5. WCRP will also focus on extremes and risks, with an emphasis on drought and flood, abrupt changes in the cryosphere, and the intensity of monsoons.

International Geosphere-Biosphere Programme. IGBP will focus on implementing its new, second-phase science plan and implementation strategy, fast-track initiatives, and its extensive collaborations with WCRP. One such example is the collaboration on Atmospheric Chemistry and Climate between the Stratospheric Processes and their Role in Climate (SPARC) and the International Global Atmospheric Chemistry (IGAC) projects. IGBP will also hold its Fourth Congress—*Sustainable Livelihoods in a Changing Earth System*, whose goal will be to take a strategic look at ways to make IGBP's activities more relevant to decisionmakers and improve participation of scientists from developing countries.

International Human Dimensions Programme. IHDP will focus on development of its science plan and strategic vision for its second decade. As important elements of this new plan, IHDP plans to improve incorporation of central social science approaches and to engage other groups including social and physical scientific communities, the wider practice community, stakeholders, and other potential producers and users of global environmental change science. The overall expectation is that the efforts of the core projects and the central secretariat will expand the overall community, improve the efforts and outputs of the program, and ultimately move toward mainstreaming of human dimensions in Earth system science.

DIVERSITAS. DIVERSITAS will not only continue its efforts through its core projects, but will, together with IGBP, undertake a fast-track initiative focused on plant functional types that are key to understanding the role of plant diversity in mediating ecosystem function and the response of plants to environmental change. DIVERSITAS will continue to serve as the lead agency for the Biodiversity task of the GEOSS and will continue to develop a draft Global Biodiversity Observation System Concept. The program expects to hold two side events at the next

Convention on Biological Diversity SBSTA related to its contributions to the development of an IMoSEB.



Earth System Science Partnership. The ESSP is implemented primarily through its four cross-cutting projects focusing on water, carbon, food and health, and integrated regional studies such as the recently launched Monsoon Asia Regional Study. GWSP is designed around three themes: magnitudes and mechanisms, linkages and feedbacks, and resilience and adaptation as well as cross-cutting themes. The project is currently preparing to launch a global digital water atlas and a global study of water flows, among other activities. GCP's activities focus around three themes under which numerous activities are organized: patterns and variability, processes and feedbacks, and carbon management as well as high-level syntheses.

SysTem for Analysis, Research and Training Programme. START will implement its project Advancing Capacity to support Climate Change Adaptation (ACCCA). START plans to complete its Assessments of Impacts and Adaptation to Climate Change (AIACC) project and to report to the Global Environment Facility on its results. START will also assist in the implementation of MAIRS, whose project office is located at the Chinese Academy of Sciences in Beijing.

US-Japan Liaison Group on Geosciences and Environment. The United States, with Japan, plans to develop the 12th US-Japan Workshop on Geosciences and Environment in FY 2008; to review the wide range of ongoing cooperative projects; and to consider and approve appropriate new cooperative projects on mutually agreed topics in the geosciences and environment with a special focus on climate and global change.

Asia Pacific Network for Global Change Research. CCSP, through its Interagency Working Group (IWG) on International Research and Cooperation, and with funding from the National Science Foundation, continued its support for the Asia-Pacific Network for Global Change Research (APN) for which Japan has the lead funding responsibility. APN approved nine new projects and continuing projects for funding in 2006/2007. APN also approved three comprehensive research projects and ten new capacity-building projects under the APN Scientific Capacity Building/Enhancement for Sustainable Development in Developing Countries (CAPaBLE) Programme, including one on the Research Needs on the Ecology of Global Change in Island Landscapes of the Republic of Palau.

APN launched its 2007/2008 call for proposals under its regular program and its CAPaBLE program with the CCSP IWG on International Research and Cooperation participating in the review process through the U.S. National Points-of-Contact.

APPENDIX A
The Climate Change Science Program Participating Agencies

APPENDIX A

THE CLIMATE CHANGE SCIENCE PROGRAM PARTICIPATING AGENCIES

The following pages present information about the contributions to the CCSP of each of the program's participating agencies:

- Department of Agriculture (USDA)
- Department of Commerce (DOC)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior (DOI)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

Principal Areas of Focus, Program Highlights for FY 2008, and Related Research are summarized for each agency.

U.S. DEPARTMENT OF AGRICULTURE

Agricultural Research Service (ARS)
Cooperative State Research, Education, and Extension Service (CSREES)
Economic Research Service (ERS)
Forest Service (FS)
Natural Resources Conservation Service (NRCS)

Principal Areas of Focus

USDA conducts and sponsors a broad range of research that supports the CCSP. USDA research focuses on questions that are relevant to decisionmakers at the Federal, state, and local levels. Areas of emphasis include evaluating risks to natural resources related to climate and other environmental change, estimating the role of forestry and agricultural activities in greenhouse gas emissions and carbon sequestration, and developing practical management strategies and approaches to manage emissions and adapt to changes. USDA's research program seeks to determine the significance of terrestrial systems in the global carbon cycle; promotes the capture and use of methane emitted from livestock waste facilities for on-farm power generation; assesses the potential of bioenergy as a substitute for fossil fuels; identifies agricultural and forestry activities that can help reduce greenhouse gas concentrations and increase carbon sequestration; quantifies the risks and benefits arising from environmental changes to agricultural lands and forests; and developes management practices that can adapt to the effects of global change, including potential beneficial and adverse effects. USDA is the lead agency responsible for preparing CCSP Synthesis and Assessment Report 4.3, *The Effects of Climate Change on Agriculture, Biodiversity, Land, and Water Resources*. USDA intends to complete the production of this report by December 2007.

Program Highlights for FY 2008

ARS's research on global change continues to focus on the carbon cycle and carbon storage, trace gas emissions and sinks, impacts of change on agricultural systems, and feedbacks among agricultural systems, weather systems, and the water cycle. During FY 2008, ARS will begin formulating its next 5-year national plan for global change research via a stakeholder-scientist workshop, creation of a national program action plan, and development of individual research projects. The research will continue the approach of building a scientific knowledge base as foundation for the development of decision-support technologies. The emphasis of ARS global change research is on enabling producers, land managers, and strategic decisionmakers to successfully mitigate the contributions of agricultural systems to climate change and adapt agricultural systems to climate change. The Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet)—a project being conducted at 30 locations across the United States—will continue measuring greenhouse gas emissions from different tillage and cropping systems, and formulating guidelines for agricultural greenhouse gas emission control and carbon sequestration. The impact of elevated atmospheric carbon dioxide on agroecosystems, such as increased pressure from weeds and invasive species, will continue as a research component. Responses of the hydrologic cycle to climate change that may affect soil water availability for agriculture and other water supplies, such as drought, will be investigated. Development of

environmentally friendly and economically feasible alternatives to the use of stratospheric ozone-depleting methyl bromide as a treatment to control pests will continue. ARS will participate in intragency and interagency working groups to ensure relevant and significant contributions to the understanding, response to, and mitigation of global change and its impact on production of food, fiber and bioenergy, and natural resources.

CSREES continues to support the USDA Ultraviolet-B Monitoring and Research Network Program. This program provides information on the geographical distribution and temporal trends of UV-B radiation in the United States. This information is critical to the assessment of potential impacts of increasing ultraviolet radiation levels on agricultural crops and forests. The program consists of both a research and climatological network. The research network provides state-of-the-art, high-resolution spectroradiometers to six sites, with cross-disciplinary use of the data. The climatological network uses less sophisticated instrumentation and will eventually total between 30 to 40 monitoring stations. Sites included in the research network enhance opportunity for collaborative research, and provide calibration benchmarks for the USDA climatological network as well as other CCSP agency ultraviolet radiation research efforts. CSREES continues to support global change research through the National Research Initiative (NRI) Competitive Grants Program and formula-funded programs. NRI includes programs for carbon and nutrient cycles, air and water quality, land-use and -cover change, ecosystems, agricultural waste management, and invasive species research spanning forest, rangeland, and agricultural ecosystems. Formula funds received through the Hatch and McIntire-Stennis Acts fund climate-related research at the land-grant universities and colleges and at multi-state institutions and state agricultural research experiment stations. CSREES is using the *CCSP Strategic Plan* in formulating priorities under the NRI program and in shaping specific grant announcements for research, education, and extension projects.

Forest Service research is concentrated on three areas. First, mitigation research aims to increase the fossil-fuel carbon removed from the atmosphere by forests and by offsets to fossil fuels provided by forest products. Second, adaptation research aims to reduce emissions of forest carbon from major disturbances by developing and evaluating methods to increase ecosystem resilience to current and future climate stresses on forests and rangelands, also thereby maintaining ecosystem health and services (e.g., timber, water supplies, biodiversity). Third, creation of decision-support systems—including monitoring, reporting, and synthesis of information—supports land managers and policymakers in adopting these new research results for optimum management of forests and rangelands under a changing environment. Within these three areas, Forest Service research works at (i) expanding understanding of the global carbon cycle in forest and rangeland ecosystems, and the consequences and feedback from the management and use of these ecosystems as they interact with the atmosphere; (ii) improving accuracy and ease of analyses of U.S. forest carbon inventory, and other monitoring and analysis systems for carbon dioxide; (iii) enhancing understanding of climate change impacts on forest health, major disturbance regimes, and ecosystem services; (iv) integrating observation and monitoring networks with process studies to better understand, forecast, and manage relationships between forest and rangelands and climate; (v) accelerating the development of management technologies to increase carbon sequestration, provide fossil-fuel offsets, enhance forest productivity, and maintain environmental quality; and (vi) providing integrated prediction models of forest dynamics under expected future changes in climate and atmospheric chemistry.

Related Research

USDA remains active in the Climate Change Technology Program (CCTP) and related research efforts. The Forest Service, NRCS, ARS, CSREES, and the Rural Development mission area support improved measurement and accounting of greenhouse gases from agriculture and forestry systems, as well as energy initiatives and renewable energy systems such as biofuels and biomass-related research and development. NRCS and the Forest Service are cooperating in development of web-based assessment tools for agricultural producers to account for benefits accruing on carbon fluxes and greenhouse gas emission from conservation practices. In addition, NRCS and the Forest Service are developing new measurement technologies, analytical techniques, and information management systems related to spatial carbon distributions. USDA also is filling gaps in ecosystem information by continuing to collect data on land use, resource conditions, and climate through the National Resources Inventory, the Forest Inventory and Analysis Program, the Soil Climate Analysis Network, and the Snowpack Telemetry system. These networks provide critical data needs on the status and condition of land use in the United States in support of CCSP research.

DEPARTMENT OF COMMERCE

Principal Areas of Focus

The National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce contribution to the CCSP.

NOAA's climate mission is: "To understand and describe climate variability and change to enhance society's ability to plan and respond." This is an end-to-end endeavor focused on providing decisionmakers a predictive understanding of the global climate system and to "translate" data so the public can incorporate the information and products into their decisions. These outcomes are achieved through implementation of a global observing system, focused research to understand key climate processes, improved modeling capabilities, and the development and delivery of climate information services. Specific objectives follow:

- Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship
- Reduce uncertainty in the information on atmospheric composition and feedbacks that contribute to changes in Earth's climate
- Provide climate forecasts for multiple time scales to enable regional and national managers to better plan for the impacts of climate variability, and climate assessments and projections to support policy decisions with objective and accurate climate change information
- Understand and predict the consequences of climate variability and change on marine ecosystems and people
- Provide information and tools to support decisionmakers in improving management of risks to the U.S. economy in sectors and areas that are sensitive to impacts from weather and climate.

NOAA relies on its Federal, academic, private, and international partners to achieve its objectives. These objectives are implemented through five distinct, yet integrated, programs: Climate Observation and Analysis, Climate Forcing, Climate Predictions and Projections, Climate and Ecosystems, and Regional Decision Support.

NIST provides measurements and standards that support accurate and reliable climate observations. NIST also performs calibrations and special tests of a wide range of instruments and techniques for accurate measurements. In FY 2008, NIST is included as a discrete element of the CCSP cross-cut for the first time, to provide specific measurements and standards of direct relevance to the program.

Program Highlights for FY 2008

National Oceanic and Atmospheric Administration

Observations and Analysis

The objective of the Climate Observations and Analysis (COA) Program is to describe and understand the state of the climate system through integrated observations, data management, and analysis. The COA Program is organized under three capabilities: Observations (atmosphere and oceans, including the Arctic), Data Management, and Analysis of the Climate System. These capabilities taken together

increase the value and utility of observations, improve the performance of models, and reduce the uncertainty of predictions. A major objective of the COA Program is to contribute to the national and global objectives outlined in the *Strategic Plan for the Climate Change Science Program*, as well as NOAA's Strategic Plan, the Strategic Plan for the U.S. Integrated Earth Observation System (IEOS), and the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan.

Activities in FY 2008 will:

- Construct high-quality reanalysis of the coupled ocean-atmosphere system from the start of the satellite era (late 1970s) through 2007.
- Begin activities under the project Explaining Climate to Improve Predictions (ECIP) to provide global climate analyses required to describe major features of 20th century climate and the capacity to address the causes of observed regional climate variations.
- Complete the U.S. Climate Reference Network (USCRN) that provides benchmark quality measurements used to monitor and evaluate long-term changes in temperature and precipitation over the United States.
- Improve the National Integrated Drought Information System (NIDIS)
  - Begin the installation a full suite of soil (moisture and temperature) measurements at all 114 USCRN stations.
  - Establish the U.S. Drought Portal (USDP) developed in conjunction with Federal partners (USGS, NASA, and USDA) and non-Federal partners (Drought Mitigation Center and the Earth Systems Integrated Enterprise).
- Enhance the Global Ocean Observing System (GOOS)
  - Sustain and continue progress toward completing the U.S. contribution to the international GOOS.
  - Complete the Argo Profiling Float Array and place additional emphasis on increasing the number of tide gage stations and ocean carbon observations, important for reduction in uncertainty of ocean sea level and the ocean carbon budget.
- Begin planning work towards the establishment of a Global Climate Observing System Reference Upper Air Network (GRUAN) to aid in enhanced climate quality upper air data including improved upper tropospheric and lower stratospheric water vapor measurements.

Climate Forcing

The objective of the Climate Forcing Program is to better quantify the information on atmospheric composition and feedbacks that contribute to changes in Earth's climate. Specifically, the program seeks to provide the understanding needed to link "emissions" to the "radiative forcing of climate change" for science-based decision support. The Climate Forcing Program is providing research (i) to understand atmospheric and oceanic processes, both natural and human-related, that affect carbon dioxide trends; (ii) to quantify the climate roles of the radiatively important trace atmospheric species such as fine-particle (aerosols), ozone, and chemically active greenhouse gases; and (iii) to understand and assess stratospheric ozone depletion. Research may be directly applied to climate projection and to policy decisions regarding carbon management, and provides timely and adequate information needed to broaden the suite of non-carbon options for addressing changes in climate forcing.

Activities in FY 2008 will:

- Integrate the research efforts of the North American Carbon Program and relevant aspects of the Ocean Carbon and Climate Change Program to better quantify and understand the carbon budget of North America and adjacent ocean basins, including terrestrial, freshwater, oceanic, and atmospheric sources and sinks that influence atmospheric CO_2 and CH_4.

- Quantify the effects of atmospheric aerosols on radiation and clouds.
- Quantify the modification of the radiation balance by non-CO_2 greenhouse gases.
- Quantify the influence of the chemistry of the lower atmosphere on both aerosols and non-CO_2 greenhouse gases.
- Study the interactions between aerosols and non-CO_2 gases, enhanced measurements of atmospheric water vapor, and interactions of pollutants with climate change.
- Execute field missions to understand the transport and properties of absorbing aerosols and their precursors to the Arctic polar region as a part of the International Polar Year (IPY) in an effort to quantify the contribution of absorbing aerosols to the melting of Arctic ice.
- Continue to re-measure key ocean properties along cross-sections in the South Atlantic and North Pacific that were last measured in 1989 and 1991, respectively, via the Repeat Hydrography Program.

Predictions and Projections

The objectives of the Climate Predictions and Projections Program are to provide climate forecasts for multiple time scales to enable regional and national managers to better plan for the impacts of climate variability, and to provide climate assessments and projections to support policy decisions with objective and accurate climate change information. This program provides the Nation with a seamless suite of environmental forecasts (i.e., outlooks and projections) on intraseasonal, seasonal, interannual, and multidecadal time scales and on regional, national, and global spatial scales. The global environment includes not only the atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere, but also land/ocean biogeochemical processes, ecosystems, atmospheric chemistry, and air quality. To achieve its objectives, this program maintains a suite of operational climate outlooks and strives to implement the next-generation operational climate outlooks and assessments by improving climate models, improving forecast generation techniques, and maintaining real-time climate monitoring data sets.

Activities in FY 2008 will:

- Emphasize model experiments designed to test potential mechanisms for abrupt climate change.
- Continue paleoclimate research on patterns, causes, and impacts of past abrupt climate events.
- Produce global analysis of tropospheric weather patterns at 6-hour time resolution that extends through the entire 20th century.
- Continue to focus on the calibration and validation of research-mode ensemble forecasting techniques for surface and subsurface hydrological parameters, especially on longer seasonal time scales.

Climate and Ecosystems

The objective of the Climate and Ecosystems Program is to understand and predict the consequences of climate variability and change on marine ecosystems. The program accomplishes this by coupling observations with information from retrospective and process studies in order to detect the impacts of climate on marine ecosystems and build an understanding of climate-ecosystem relationships. The goal of the program is to develop climate-related forecasts of changes in fishery, coastal, and coral reef resources, and of human and animal threats (e.g., harmful algal blooms). The forecasts provide users and managers of ocean and coastal resources the information they require to adapt to changing climate regimes.

Activities in FY 2008 will:

- Collect observations, conduct research, and synthesize results to increase the understanding of regional climate impacts on marine ecosystems.
- Initiate development of biosensors for harmful algal blooms and pathogen for eventual incorporation in observing ssystems.

Regional Decision Support

The Regional Decision Support (RDS) Program provides information and tools to support decisionmakers in improving management of risks to the U.S. economy—and taking advantage of opportunities—in sectors and areas that are sensitive to impacts from weather and climate. Effective incorporation of climate information provides decisionmakers with the data, analysis, and new knowledge that can help them achieve the best possible outcome with regard to a varying climate. This includes the socioeconomic effects of drought, El Niño and La Niña events, sea-level rise, and other high-impact climate events. RDS addresses an increased demand for traditional climate services, such as data and forecast dissemination and customer support, as well as identifying and satisfying new requirements for decision support in sectors such as water, fire, emergency preparedness, health, transportation, energy, coastal, urban, and ecosystem management. Demand for increased services is met through research into decisionmaker needs and prototype product development, transition of research products into application and operations, and operational delivery and support of climate services.

Activities in FY 2008 will:

- Produce the following CCSP synthesis and assessment products slated for publication in 2008:
  - *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure* (2.4)
  - *Climate Projections based on Emissions Scenarios for Long-Lived Radiatively Active Trace Gases and Future Climate Impacts of Short-Lived Radiatively Active Gases and Aerosols* (3.2)
  - *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands* (3.3)
  - *Decision-Support Experiments and Evaluations using Seasonal to Interannual Forecasts and Observational Data* (5.3).
- Develop methods, models, and mechanisms for integrating climate information into analyses of the social and economic ramifications of drought as well as the policy and decisionmaking processes in the face of drought.
- Further development of the National Integrated Drought Information System (NIDIS).

National Institute of Standards and Technology

The National Institute of Standards and Technology provides measurements and standards that support accurate and reliable climate observations. In FY 2008, NIST will address critical gaps in climate change science that are limiting long-term climate policy decisionmaking by:

- Resolving discrepancies in satellite measurements of radiation, including solar irradiance, reflected solar radiation, outgoing longwave radiation, and surface radiation
- Providing critical information about aerosols and atmospheric components believed to play a major role in global climate change.

DEPARTMENT OF DEFENSE

Principal Areas of Focus

The Department of Defense—while not supporting dedicated global change research—continues a history of participation in the CCSP through sponsored research that concurrently satisfies national security requirements and stated goals of the CCSP. All data and research results are routinely made available to the civil science community. DOD science and technology investments are coordinated and reviewed through the Defense Reliance process and published annually in the *Defense Science and Technology Strategy*, the *Basic Research Plan*, the *Defense Technology Area Research Plan*, and the *Joint Warfighting Science and Technology Plan*.

Program Highlights for FY 2008

Satellite Sensors and Observations

DOD will fund 50% of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS), as a result of the convergence of national sensing suites. NPOESS will monitor global environmental conditions, and collect and disseminate data related to weather, atmosphere, oceans, land, and near-space environment. The NPOESS Program is managed by the tri-agency Integrated Program Office run by DOC, DOD, and NASA.

Global Observations and Models

The Navy is a principal member of the National Oceanographic Partnership Program, incorporating the Integrated Ocean Observing System and associated data management and communications, the Global Ocean Observation System, the Global Ocean Data Assimilation Experiment (GODAE), and the National Federation of Regional Associations (<www.ocean.us/> and <usnfra.org>). This broad partnership of agencies collaborates in the development and demonstration of integrated ocean observations systems, data management systems, and eddy-resolving, real-time global and basin-scale ocean prediction systems. As part of GODAE, the Navy funds development of the Hybrid Coordinate Ocean Model (HYCOM), a predictive model which runs efficiently in parallel computing environments and includes sophisticated techniques for assimilation of satellite and *in situ* observations. The U.S. GODAE data server (see <usgodae.org>) is also funded by the Navy. The goal of this project is to develop and implement a comprehensive data management and distribution strategy that allows easy and efficient access to HYCOM-based ocean prediction system outputs to coastal and regional modeling sites, making them available to the wider oceanographic and scientific community, including climate and ecosystem researchers, and the general public especially students in middle and high schools. This is accomplished through a data-sharing system that uses existing open source software packages to distribute the ocean prediction system data via the Internet.

The Coupled Boundary Layers Air-Sea Transfer Defense Research Initiative focuses on processes that occur in the oceanic and atmospheric wave boundary layers (i.e., regions influenced by ocean surface waves). This Office of Naval Research program combines observational and modeling components in all of its investigations. These investigations will focus on processes that couple the turbulent atmospheric and oceanic boundary layers across the interface through the exchange of momentum, mass, and heat. The observational components include *in situ* investigations of ocean-atmospheric turbulence and mean

flow from fixed towers and moorings, remote sensing of 2- and 3-D structure of the boundary layers and ocean surface, appropriate surface wave measurements with particular emphasis on small-scale and breaking waves, and Autonomous Underwater Vehicle and aircraft-based measurements. A significant outcome of the program is a coupled ocean-wave-atmosphere model for hurricanes which shows significant promise in intensity forecasts. This may lead to a better representation of these systems in climate simulations.

Results from the Monterey Bay 2006 (MB 06) experiment are being analyzed. This program builds on earlier work of the Autonomous Ocean Sampling Network I and II programs to demonstrate the coordination of a diverse collection of unmanned observing platforms within the context of data-assimilation models to form an effective ocean observing and undersea monitoring system. MB 06 is an integrated experiment that involves the interaction and coordination of four related but distinct programs: Adaptive Sampling and Prediction (ASAP), Undersea Persistent Surveillance (UPS, or UPS/PLUSNet), Assessing the Effects of Sub-Mesoscale Ocean Parameterizations (AESOP), and Layered Organization in the Coastal Ocean (LOCO).

Polar Regions Research

A priority in the CCSP research plan has been the polar and sub-polar regions, which have exhibited more rapid changes than the lower latitudes. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) is America's lead Federal laboratory for polar and sub-polar research. The CRREL research program responds to the needs of the military, but much of the research also benefits the civilian sector and is funded by non-military customers such as NSF, NOAA, NASA, DOE, and state governments. DOD research has examined impacts of climate change on retreating Arctic sea ice—defining the requirements for U.S. Coast Guard icebreaking ships for the next 30 years. Satellite data show that the extent of Arctic sea ice has decreased by about 10%, and the sonar data collected by U.S. Navy submarines in the Arctic between 1957 and 2000 show the average ice thickness has decreased between 33 and 42%. CRREL and the University of Alaska are developing a web-accessible Alaska Engineering Design Information System—an analytic toolkit for engineers that presents a broad array of geospatial terrestrial, oceanic, and atmospheric environmental data in a geographic information system.

The Navy, through its participation in the National Oceanographic Partnership Program, is funding research related to climate change under the call for proposals "Coastal Effects of a Diminished-Ice Arctic Ocean." The funded efforts will explore ocean observing system strategies for the Alaska Beaufort and Chukchi Seas, changes in the circulation and wave dynamics of the coastal arctic, the impact on coastal production and sediment transport, and the measurement and prediction of seasonal changes in sea ice cover in the Beaufort and Chukchi Seas.

Related Research

Other DOD-sponsored research and supporting infrastructure also contribute to observing, understanding, and predicting environmental processes related to global change. Associated research programs include theoretical studies and observations of solar phenomena, monitoring and modeling of unique features in the middle and upper atmosphere, terrestrial and marine environmental quality research, and energy conservation measures. DOD's continued investment in environmental infrastructure—such as the Oceanographic Research Vessel Fleet, and the various services' operational oceanographic and meteorological computational centers—will continue to provide data and services useful to CCSP.

DEPARTMENT OF ENERGY

Principal Areas of Focus

Research supported by DOE's Office of Science is focused on the effects of energy production and use on the global climate system, primarily through studies of climate response to changes in greenhouse gas and aerosol concentrations. Research covers three program areas: 1) climate change modeling, 2) climate forcing, and 3) climate change response.

Program Highlights for FY 2008

DOE will continue support of climate change research at its National Laboratories and other public and private research institutions, including universities. In support of CCSP, the DOE Office of Science's Climate Change Research Program will continue to provide the data and predictive understanding that will enable objective, scientifically rigorous assessments of the potential for, and consequences of, human-induced climate change.

Climate Change Modeling

DOE continues to develop, improve, evaluate, and apply fully coupled atmosphere-ocean-sea ice-land surface general circulation models (GCMs) that simulate climatic variability and change over decadal to centennial time scales. As one of its contributions to the suite of synthesis and assessment products (SAPs) being prepared by CCSP, DOE is leading the effort on SAP 3.1, *Climate Models: An Assessment of Strengths and Limitations for User Applications*.

In FY 2008, DOE researchers will continue analysis of multi-model ensemble runs under various forcing scenarios. IPCC Fourth Assessment Report model simulations from major national and international high-end modeling centers are currently archived at Lawrence Livermore National Laboratory (LLNL) / Program for Climate Model Diagnosis and Intercomparison (PCMDI), and made accessible to the climate research community. Under the DOE-wide Scientific Discovery through Advanced Computing (SciDAC) initiative, DOE will continue to support model development of the Community Climate System Model (CCSM) to incorporate atmospheric chemistry and coupled biogeochemistry, in addition to improved physics and dynamics. DOE will also continue ongoing development of high-resolution comprehensive coupled GCMs that incorporate more accurate and verified representations of clouds and other important climatic processes. DOE will continue support of the development of a global cloud resolving model. New activity in the area of abrupt climate change will be initiated.

Climate Forcing

Collection and analysis of data from DOE's Atmospheric Radiation Measurement (ARM) Cloud and Radiation Test Bed (CART) sites will continue in FY 2008 to improve understanding of the radiative transfer processes in the atmosphere and to formulate better parameterizations of these processes, especially cloud and aerosol effects for use in climate models. DOE will also report on the results of two major campaigns: the Cloud and Land Surface Interaction Campaign (CLASIC) and the 9-month deployment of the ARM Mobile Facility (AMF) in the Black Forest region of Germany. The latter is part of a large international campaign, Convective and Orographically Induced Precipitation Study (COPS). The COPS region can be characterized by significant orographic precipitation with most of the

summertime precipitation being convective. The experiment is designed to improve the prediction of precipitation in this environment. CLASIC was designated as the core of a FY 2007 priority for the interagency Water Cycle Interagency Working Group of the CCSP. The goal of CLASIC is to advance understanding of how land surface processes influence cumulus convection and to produce improved parameterizations of cumulus convection and associated parameterizations of land surface processes. Cumulus convection is an important component in the atmospheric radiation budget and hydrologic cycle of the Southern Great Plains, particularly during the summertime growing season. In 2008, ARM will deploy the AMF to China and will conduct two experiments that contribute to the International Polar Year (IPY). The AMF deployment to China will study the aerosol indirect effect. Aerosols in China have exceptionally high loading and diverse properties whose influence has been detected across the Pacific Rim. The first IPY experiment, the Indirect and Semi-Direct Aerosol Campaign (ISDAC), is designed to determine the semi-direct effect of the aerosol on the clouds in the arctic. The second IPY experiment, Routine *In Situ* Cloud and Aerosol Measurements at the North Slope of Alaska, will conduct intensive cloud and aerosol observations that can be used to develop and evaluate new model parameterizations. In FY 2008, the ARM science program will also focus on the development of new cloud schemes and improvement of cloud-radiation parameterization schemes. Special measurements from the Tropical Warm Pool International Cloud Experiment (TWP-ICE), COPS, the aerosol study in China, and CLASIC will give scientists ample opportunities to validate and improve radiation-cloud-aerosol processes representations in climate models.

DOE's Atmospheric Science Program (ASP) will continue research in FY 2008 to reduce uncertainties in aerosol radiative forcing of climate. This research includes laboratory and field research on key processes individually and as encountered in "real world" environments. Acquired data are used to develop and test predictive parameterization schemes or models for aerosol properties and their effect on radiative transfer in the atmosphere. Field and laboratory observations are also used to interpret and extend the results of process model simulations. Current priority atmospheric processes under study include transformations and properties of carbonaceous aerosols, especially secondary organic aerosols, that are poorly predicted by current atmospheric models. Also important are processes controlling new particle formation and growth, as well as the properties that affect their activation as droplet and crystal nuclei. During FY 2008, technical planning and preparations will be finalized for ASP participation in a major collaborative interagency field campaign in October 2008 (VOCALS) aimed at measuring interactions of aerosols with clouds in a region that is impacted both by pristine and polluted air masses. One specific objective of ASP activity is to test new process models of drizzle formation that show promise for inclusion into global climate models. Analysis of data from prior field studies will continue, principally from the FY 2006 campaign conducted in and around Mexico City to examine the properties and processes of aerosols emanating from a large metropolitan area, and from the FY 2007 CHAPS campaign, that examined interactions of aerosols with fair-weather cumulus clouds.

DOE's carbon cycle research will continue to improve understanding of the role of terrestrial ecosystems in the global carbon cycle, with attention on processes that control the rate of CO_2 exchange with ecosystems and that affect the rate of atmospheric increase and climate forcing by this greenhouse gas. Research in FY 2008 will address the questions and elements described in Chapter 7 of the *CCSP Strategic Plan*. DOE's Terrestrial Carbon Processes (TCP) research will continue to contribute to the North American Carbon Program (NACP) through support of experiments, observations, and modeling of atmospheric CO_2 and the terrestrial carbon cycle. As recommended by the Biological and Environmental Research Advisory Committee (BERAC) review, research will continue to focus on the

AmeriFlux network of observations, experiments, modeling, and syntheses. Temporal and spatial observations of gross and net carbon dioxide fluxes, and real-time information on ecosystem carbon states and sinks, will be made available to researchers that are investigating regional CO_2 exchange, continental-scale carbon sinks and sources, and carbon cycle-climate relationships. DOE will also support the NACP strategy of a model-based comparison of "bottom-up" (distributed ecosystem models driven by land surface and meteorological information) and "top-down" (inferring spatially distributed surface fluxes from atmospheric measurements) approaches to estimating ecosystem carbon dioxide fluxes for different regions of the United States. DOE will provide information on biogeochemical, physiological responses and terrestrial ecosystem feedbacks related to climate change as part of joint carbon cycle-climate change research to improve simulation models.

Climate Change Response

DOE will continue to design, implement, and maintain large-scale and long-term experimental field manipulations of environmental factors affected by energy production in important North American ecosystems. This includes support of Free-Air CO_2 Enrichment (FACE) experimental facilities for study of the response of U.S. forests to elevated atmospheric concentrations of carbon dioxide and/or ozone. The goal is to understand, and be able to predict, effects of environmental changes associated with energy production on the structure and functioning of terrestrial ecosystems. The research focuses on the physiology, growth, and reproduction of plants, animals, and microbes; nutrient and water cycling in ecosystems; plant community dynamics; plant-insect and plant-microbe interactions; and acclimation and adaptation of plants, animals, microbes, and whole ecosystems to environmental change. As recommended by BERAC, DOE will begin to wind down the FACE experiments in FY 2008.

Ongoing experimental research will be continued in FY 2008, including field manipulations of temperature, precipitation and soil moisture, carbon dioxide concentration, and/or ozone concentration in a range of terrestrial ecosystems, including boreal forest, temperate shrublands, temperate grasslands, temperate woodlands, and temperate deciduous and evergreen forests. New warming experiments will be initiated in the ecotone separating the temperate and boreal forest biomes and at the alpine tree line. Warming experiments to evaluate potential effects of climatic change on important insect populations will also be initiated. Such experiments will provide the data and information needed to evaluate (test) the ability of ecological models to realistically predict effects of climatic change on terrestrial ecosystems; such models form the basis of most assessments of potential effects of climatic change on terrestrial ecosystems.

The DOE Integrated Assessment of Global Climate Change Research Program will continue to support research on the nature and magnitude of human-earth systems interactions, providing scientific insights into the integrated drivers of climate change and the impacts of and adaptations to those changes. With improvements to models of global economies and the corresponding energy-driven technologioes that emit greenhouse gases, and with similar improvements and stronger coupling to the underlying models of the natural earth systems, the program will deliver improved science-based tools for determining safe levels of greenhouse gas emissions and understanding of the relative efficiencies and impacts of potential mitigation strategies. In FY 2008 and in response to a FY 2007 review of the program by BERAC, the program will shift emphasis and take on the important and challenging task of strengthening representations of impacts and adaptations in integrated assessment models. There is a strong interagency dimension to this challenge and the program began in FY 2007, and will continue in FY 2008, efforts to build multi-agency collaborations to realize this objective. In FY 2008, the program will apply new

mathematical and computational approaches to integrated assessment in order to reveal deeper insights into complex human-earth systems interactions and process dynamics while taking advantage of the more detailed, underlying models of the natural systems. In FY 2008, work will continue on the two large integrated assessment models funded by the program to improve their representation of renewable energy derived from biological sources. The portrayal of uncertainty in emission scenarios will also be studied to help identify methods that represent important variability with a small number of alternative scenarios. Also in FY 2008, select scenarios will be developed and analyzed with the goal of delivering key emissions and land-use parameters to Earth systems modelers for calibration and bounding of emerging models and for use in climate research.

DOE will also continue support of its Global Change Education program in FY 2008, including support of undergraduate and graduate students through the DOE Summer Undergraduate Research Experience (SURE) and the DOE Graduate Research Environmental Fellowships (GREFs). Support will also be continued for the Carbon Dioxide Information and Analysis Center (CDIAC) to enable it to respond to data and information requests from users all over the world who have a need for data on, for example, greenhouse gas emissions and concentrations.

Related Research

DOE plays a major role in carbon sequestration research to reduce atmospheric concentrations of energy-related greenhouse gases, especially carbon dioxide, and their net emissions to the atmosphere. The research builds on, but is not part of, the CCSP. It focuses on both developing the scientific information needed to enhance the natural sequestration of excess atmospheric carbon dioxide in terrestrial systems, and assessing the potential environmental consequences and ancillary benefits of that enhanced sequestration. It also includes research to develop biotechnological approaches for sequestering carbon either before or after it is emitted to the atmosphere. Funding for DOE's carbon sequestration research is part of the Climate Change Technology Program (CCTP). CCTP also provides related research funding to support a balanced and diversified portfolio of advanced technology R&D, focusing on energy-efficiency enhancements; low greenhouse gas emission energy supply technologies; carbon capture, storage, and sequestration; and technologies to reduce emissions of non-CO_2 gases. Together, CCSP and CCTP will help lay the foundation for future progress. Advances in the climate change sciences under CCSP can be expected to improve understanding about climate change and its impacts. Similarly, advances in climate change technology mitigation under CCTP can be expected to bring forth an expanded array of advanced technology options at a lower cost that will reduce greenhouse gas emissions.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

National Cancer Institute (NCI)
National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS)
National Institute of Environmental Health Sciences (NIEHS)

Principal Areas of Focus

The Department of Health and Human Services supports a broad portfolio of research related to environmental health and the health effects of global change. Included in the U.S. Climate Change Science Program is research supported by the National Institutes of Health (NIH) that focuses on exposure to ultraviolet (UV) and near-UV radiation. The principal objectives of the NIH institutes supporting this research include an increased understanding of the effects of UV and near-UV radiation exposure on target organs (e.g., eyes, skin, immune system), the molecular changes and genetic susceptibilities that lead to these effects, and the development of strategies to prevent initiation or promotion of disease before it is clinically defined.

In addition to UV and near-UV radiation research, HHS also supports other research related to the health effects of global change. For example, the National Institute of Environmental Health Sciences (NIEHS) supports research on the health effects of 1) air pollution and temperature, 2) agricultural chemicals, and 3) materials used in new technologies to mitigate or adapt to climate change. In addition, the Centers for Disease Control and Prevention (CDC) is engaged in a number of activities related to climate change, such as emerging and reemerging infectious diseases. Such related research is growing in importance.

Program Highlights for FY 2008

The NIEHS program supports grants and intramural projects that investigate the effects of UV exposure on the immune system, aging process, sensitive tissues such as the retina and skin, and methods to reduce these harmful effects. Examples of research include projects that will characterize the DNA-damaging and mutagenic properties of UV-A radiation, a component of the solar spectrum that has been linked to melanoma, then attempt to find a molecular link between exposure to sunlight and melanoma.

The National Toxicology Program (NTP) funded and operated by NIEHS is carrying out a systematic analysis of commercially available sunscreens to characterize several nanoscale metal oxides (e.g., titanium, zinc) currently used with regard to their dermal penetration and photocatalytic action. Careful attention is being paid to determining critical aspects of size, surface area and chemistry, crystallinity, and biopersistence in relation to both dermal penetration and potential for toxicity in the presence or absence of simulated solar light.

The National Cancer Institute (NCI) is supporting a wide range of studies to characterize the etiology, biology, immunology, and pathology of a variety of changes in the skin (morphological effects that might precede skin cancer), including photoaging, non-melanoma skin cancers, and melanoma caused by exposure to UV radiation. In addition, NCI is supporting studies to reduce the risk of melanoma and

non-melanoma skin cancer through the development of clinically useful primary and secondary prevention strategies. One study is developing, implementing, and evaluating solar protection programs for middle school children. The interventions target school, community, recreation and beach settings, primary care practices, and parents. The interventions are based on theories that include social influence, psychological factors, and cognitive decisional factors in adolescence. Other studies are looking at the role of UV light exposure in the development of second malignant neoplasms in cancer survivors.

The National Institute of Arthritis, Musculoskeletal, and Skin Diseases (NIAMS) supports basic and clinical research on the effects of UV-A and UV-B radiation on skin. Examples of current studies include research that examines the ability of green tea polyphenols to protect against UV-B-induced skin cancers through the augmentation of the repair of UV-damaged DNA. Another study looks at the effects of UV-B radiation on the stability of cell cycle regulatory proteins, yielding insight into the mechanisms by which UV-B radiation increases the risk of non-melanoma skin cancer. There are also studies that are testing the role of acquired homoplasmic mitochondrial (mtDNA) changes in the process of photoaging and aberrant keratinocyte hyperplasia, novel biosynthetic pathway for secosteroids (such as vitamin D) in the skin, as well as the expression of keratins induced whenever skin tissue is subjected to injury, UV exposure, and other challenges. Previous studies in this area have included research to better understand how vitamin D3 is made and processed in the skin. These chemical reactions require ultraviolet radiation. There was also a study on the role of overexposure to UV light in the development and exacerbation of vitiligo, a pigmentary disorder that leaves patients with disfiguring white skin patches that increase in size over time. Another patient-oriented research project involves the molecular mechanisms for the exaggerated response to UV-B of a polymorphism that is strongly associated with a photosensitive form of lupus erythematosus. Research is also conducted on the effect of UV-R on Langerhans cells, star-shaped cells in the germinative layer of the epidermis, and on immunity in skin. Using gene array technology, scientists have identified 52 genes that are consistently up-regulated by UV-R.

Related Research

CDC conducts public health research on a wide-range of topics that are associated with climate change ranging from vector-borne diseases to human health effects of heat waves. CDC has established a long-term national surveillance system to monitor enzootic transmission activity and patterns across the entire country. For West Nile virus (WNV), the agency is conducting research on the potential human health burdens and transmission characteristics of the disease in Guatemala to see how climate change may influence the distributions of arboviruses in the Western Hemisphere. CDC is conducting interrelated investigations of the complex ecology of WNV to better understand its distribution in the United States. Scientists from CDC are working with colleagues from around the world to analyze the key climatic variables and other ecological factors that impact the transmission and distribution of other zoonotic diseases including Chikungunya virus, Japanese encephalitis, Rift Valley Fever, and plague. Researchers are developing mathematical models that relate changing weather conditions, among other factors, to the risk of infectious diseases in humans, including hantavirus, lyssaviruses, and filoviruses.

CDC is also developing models to predict mortality risks from the most direct effects of climate change—heat waves. Collaborations with university colleagues on four current projects use remote sensing data to determine urban neighborhoods and populations most at-risk for deaths during an extreme heat event. Research is also focusing on the knowledge, attitudes, and beliefs of the public on health issues related to climate change to effectively craft health education messages.

DEPARTMENT OF THE INTERIOR

Principal Areas of Focus

DOI/USGS research contributes directly to CCSP strategic goals, principally through studies designed to understand the interactions between climate, earth surface processes, ecosystems, and human activities on time scales ranging from years to millennia. By combining the expertise of hydrologists, geologists, biologists, geographers, and remote-sensing scientists within one organization, USGS supports truly interdisciplinary research in the following major focus areas:

- Studies of climate history and impacts on landscapes and ecosystems
- Hydrologic impacts of climate change
- Carbon cycle science
- Land-use and land-cover changes
- Decision-support research and development.

The goal of global change research at USGS is to improve knowledge and understanding of the Earth's past and present climate and environment, the forces bringing about changes in the Earth's climate, and the sensitivity and adaptability of natural and managed ecosystems to climate changes.

Program Highlights for FY 2008

Earth Surface Dynamics

The Earth Surface Dynamics program has the following research objectives:

- Document the nature of climatic and environmental change and variability on time scales ranging from years to millennia.
- Develop fundamental understanding of interactions between climate, earth surface processes, and marine and terrestrial ecosystems on time scales ranging from years to millennia.
- Seek to understand impacts of climate change and variability on landscapes and marine and terrestrial systems.
- Model and anticipate the effects of climate change and variability on natural and human systems.
- Provide information on the relative sensitivity, adaptability, and vulnerability of ecosystems, resources, and regions to climatic change and variability to support land and resource management and policy decisions.

Geographic Analysis and Monitoring

Research is directed to the understanding of the rates, causes, and consequences of landscape change over time. This knowledge is used to model processes of landscape change and to forecast future conditions. Studies are designed to document and understand the nature and causes of changes occurring on the land surface; to assess the impacts of land surface changes (including urbanization) on ecosystems, climate variability, biogeochemical cycles, hydrology, and human health; and to develop the best methods to incorporate science findings in the decisionmaking process.

Hydroclimatology

Research on effects of climate change and variability on the hydrologic cycle focuses on characterizing, and developing predictive methods related to, the hydroclimatology of North America. This includes

identification of seasonal variations in regional streamflow in relation to atmospheric circulation (for regional streamflow prediction and flood/drought hazard assessment); the linkage between atmospheric circulation and snowpack accumulation (for forecasting spring and summer water supply in the western United States and for flood forecasting), as well as glacier mass balance; and the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions (to discriminate natural from human-induced effects on such systems). It also includes documenting the long-term behavior of hydrologic systems in response to past climatic variations and changes (from decades to hundreds of thousands of years) as well as more recent (decadal) hydrologic trends. The program maintains an active effort to develop improved representations of terrestrial hydrologic processes in general circulation and regional climate models. In broad terms, these activities are aimed at improving statistical and deterministic methods for predicting hydrologic hazards and related environmental conditions on monthly to interannual time scales.

Carbon Cycle

USGS conducts a broad range of carbon cycle research focused on North America, which includes:

- *Assessment of Carbon Stocks and Soil Attributes*—Determining the spatial distribution of carbon in the terrestrial environment in relation to historical natural and human processes, as a basis for initializing dynamic models of soil carbon. Measuring soil chemistry has focused on the Mississippi and Delaware River basins, the latter in collaboration with the USDA Forest Service Forest Inventory and Analysis Program.
- *Carbon Sequestration in Sediments*—Studying the re-deposition of eroded soils and sediments (and their associated organic carbon) which sequesters large quantities of carbon, buried at the base of slopes and in wetlands, riparian areas, and reservoirs.
- *Carbon Sequestration in Wetlands*—Field and laboratory process studies, spatial analysis, and modeling are being used in wetlands of the Lower Mississippi River Valley and the Prairie Pothole Region to quantify the influence of land-use change on carbon sequestration and greenhouse gas emissions and to identify environmental factors controlling carbon sequestration. These studies will provide recommendations and decision-support tools to resource managers to maximize carbon sequestration benefits consistent with DOI goals for restoration of ecosystem services such as habitat, flood storage, and water quality.
- *Landscape Dynamics and Vegetation Change*—Examining the long-term dynamics of vegetation change in relation to climate change and variability. A detailed history of vegetation change in the western United States is being constructed. Past changes are used to model vegetation response to climatic variables. This knowledge is applied in forecasting the effects of future climate change on the distribution of vegetation in the western United States.
- *Fate of Carbon in Alaskan Landscapes*—Expanding process studies and modeling to better understand both the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration. Cold region forests (boreal ecosystems) contain large carbon reserves that are highly susceptible to changes in climate.
- *Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface*—Employs field measurements, remote sensing, and modeling of carbon fluxes to develop estimates of gross primary productivity, respiration, and net ecosystem exchange at flux tower sites, and uses remotely sensed data to extrapolate these carbon fluxes to ecoregions.

Changes in Ecosystems

USGS global change research on ecosystems aims to determine the sensitivity and response of ecosystems and ecological processes to environmental factors, including existing climate and natural

and anthropogenic impacts, at the local, landscape, regional, and continental level; to assess and predict how future environmental conditions may affect the structure, function, and long-term viability of natural and human-impacted ecosystems; and to provide scientific knowledge and technologies needed for conservation, rehabilitation, and management of sustainable ecosystems. Current USGS ecosystems research focuses on:

- The relative sensitivity of biological resources and geographic areas of the Nation to global changes in order to detect early changes and prioritize action
- The causal mechanisms underlying ecosystem responses to global change
- The role of scaling in understanding and managing the spatial and temporal responses of biological systems to global change
- Development and testing of management options for adapting to the effects of global change and minimizing undesired effects of global change.

Satellite Data Management and Dissemination

USGS operates and continually enhances the capabilities of the Center for Earth Resources Observation System (EROS) to serve as the National Satellite Land Remote-Sensing Data Archive, by maintaining existing data sets, adding new ones, and converting older data sets from deteriorating media to modern, stable media. The archive's holdings are used for environmental research, land management, natural hazard analysis, and natural resource management and development with applications that extend well beyond U.S. borders. The worldwide community of archive users includes personnel in Federal, State, local, and tribal governments, researchers at academic institutions, private enterprise, and the public.

Land Use and Land Cover

The Land Cover Characterization Program was started in 1995, to address national and international requirements for land-cover data that were becoming increasingly sophisticated and diverse. The goal is to be a national and international center for excellence in land-cover characterization, via:

- Development of state-of-the-art multiscale land-cover characteristics databases used by scientists, resource managers, planners, and educators (global and national land cover)
- Contribution to the understanding of the patterns, characteristics, and dynamics of land cover and land-cover change across the Nation and the Earth (urban dynamics and land-cover trends)
- Pursuit of research that improves the utility and efficiency of large-area land-cover characterization and land-cover characteristics databases
- Serving as a central facility (Land Cover Applications Center) for access to, or information about, land-cover data.

Related Research

DOI also sponsors contributing research programs addressing the collection, maintenance, analysis, and interpretation of short- and long-term land, water, biological, and other geological and biological processes and resources through dispersed observing networks; research in land use and land cover, including creation of maps and digital data products; and inventorying and monitoring of biological habitats, resources, and diversity.

DEPARTMENT OF STATE

Principal Areas of Focus

Through Department of State annual funding, the United States is the world's leading financial contributor to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Intergovernmental Panel on Climate Change (IPCC)—the principal international organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate change initiatives, including: the Asia-Pacific Partnership on Clean Development and Climate, the Carbon Sequestration Leadership Forum, the Group on Earth Observations, the Methane-to-Markets Partnership, the International Partnership for a Hydrogen Economy, and the Generation IV International Forum.

Program Highlights for FY 2008

During FY 2008, DOS will continue to support the activities of the UNFCCC and the IPCC, and will advance the bilateral and multilateral partnerships for global climate science, technology, and observation that were undertaken in the FY 2006-2007 time frame.

DEPARTMENT OF TRANSPORTATION

Principal Areas of Focus

The Department of Transportation conducts research and uses existing science to improve decisionmaking tools to address climate change. USDOT supports research that 1) examines the potential impacts of climate variability and change on transportation infrastructure and services; 2) increases energy efficiency and reduces greenhouse gases; and 3) improves transportation greenhouse gas data and modeling. USDOT has many programs that have either direct or indirect climate benefits and is working to develop cross-modal strategies to reduce greenhouse gas emissions.

USDOT's Climate Change Center is the Department's focal point for information and technical expertise on climate change. The Center coordinates research, policies, and actions related to transportation and climate change with USDOT's component organizations. Supporting USDOT's core goals of safety, mobility, environmental stewardship, and security, the Center promotes comprehensive approaches to reduce greenhouse gases, to prepare for the potential impacts of climate change, and to develop necessary adaptations to transportation operations and infrastructure. The Center's three primary objectives are to:

- Promote cost-effective strategies that reduce greenhouse gas emissions while supporting improved transportation safety, mobility, and efficiency
- Foster strategies to avoid, mitigate, or adapt to the potential impacts of climate change on the transportation system
- Provide leadership to the transportation community and coordinate USDOT multi-modal activities on climate change.

The Center supports CCSP goals through these objectives. Specifically, the Center aims to inform CCSP Goal 4 by identifying and providing scientific inputs for evaluating adaptation options and CCSP Goal 5 by supporting adaptive management and planning for physical infrastructure sensitive to climate variability and change.

In addition to participating in the Center, the Federal Aviation Administration (FAA) has independent programs to assess and identify potential measures to reduce fuel consumption and greenhouse gas emissions. FAA conducts research to support CCSP Goal 2, leveraging research with other U.S. Government agencies to reduce uncertainties surrounding aviation emissions and their effect on climate change. For example, FAA research through the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence addresses the impact of aircraft contrails on climate change. FAA also has a number of ongoing operational initiatives to reduce fuel consumption and thus the amount of greenhouse gas emissions produced by aviation, including improved air traffic management, reduced vertical separation minimums, and the voluntary airport low emissions program that assists in deploying low emissions technology to airport operations. FAA also participates heavily in the work program of the International Civil Aviation Organization's Committee on Aviation Environmental Protection, and lends technical expertise and data to the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

Program Highlights for FY 2008

USDOT's Climate Change Center is undertaking several research projects that support CCSP Goals 4 and 5:

- Refining a tool to allow comparative analysis of emissions from different modes of transportation, including aviation, automobile, marine, and diesel transportation
- Exploring adaptation to potential impacts of climate change by partnering with the Transportation Research Board of the National Academies
  - Reexamine the role of design standards for transportation infrastructure in light of potential impacts from climate change
  - Develop operational responses to potential climate change impacts
  - Review approaches to decisionmaking under uncertainty
- Conducting an emissions analysis of freight transport, comparing land-side and water-side short-sea routes to develop and demonstrate a decision modeling tool
- Determining the potential effects of sea level rise on national transportation infrastructure.

The Center sponsors CCSP Synthesis and Assessment Product 4.7, *Impacts of Climate Variability and Change on Transportation Systems and Infrastructure–Gulf Coast Study*. This project—initiated under the President's Climate Change Research Initiative—is a joint research effort with USGS. A Federal Advisory Committee was formed in 2006, and Phase I was completed in 2007. Phase I provided an integrated overview of infrastructure sensitivities in the region. This document is scheduled for completion in the second quarter of FY 2008.

The Office of the Secretary is funding several projects, including a *Best Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation* designed for use by companies and individual freight operators.

Related Research

Many of DOT's programs have ancillary climate benefits:

- The Federal Highway Administration has numerous programs to prepare the highway system for weather irregularities and reduce air pollutants:
  - *Road Weather Management Program*. This program seeks to better understand the impacts of weather on roadways. The Clarus initiative will develop and demonstrate a national integrated surface transportation road weather observing, forecasting, and data management system.
  - *Congestion Mitigation and Air Quality (CMAQ) Improvement Program*. The CMAQ program provides over $8.6 billion in funds over a period of 5 years (2005-2009) to state transportation agencies to invest in projects that reduce emissions from transportation-related sources.
  - *Idle-Reduction Activities*. DOT, EPA, and DOE have provided funding for the implementation of idle-reduction projects around the country (both on-board and off-board technologies) for transportation, air quality, and energy stakeholders. The projects have resulted in reductions in criteria air pollutants, such as NO_x, as well as reductions in CO_2 emissions. This initiative has expanded to include idling emissions from marine, rail, and off-road heavy-duty engines.

- The National Highway Traffic Safety Administration sets new Corporate Average Fuel Economy standards for light trucks, increasing energy efficiency and thus decreasing greenhouse gas emissions.
- FAA continues to develop a suite of environmental analytical tools—including the System for assessing Aviation's Global Emissions (SAGE), a component of the Aviation Environmental Design Tool (AEDT) and the Aviation Portfolio Management Tool (APMT) in order to assess cost-effective options to limit or reduce fuel consumption and greenhouse gas emissions. This component of AEDT generates aviation fuel consumption and emissions inventories for baseline conditions based upon operational data, estimates future emissions based upon fleet forecasts including technology advances, and also estimates future emissions based upon projections for changes in the National Air Space including operational improvements. The tool also has the capability to assess the influence of market-based measures to reduce fuel consumption and thus greenhouse gas emissions. Data from AEDT/SAGE is used to calculate the FAA's Flight Plan aviation fuel efficiency goal.
- The Federal Transit Administration (FTA) Fuel Cell Program has researched and demonstrated fuel cell bus technology since the mid-1990's. FTA also conducts alternative fuels research.
- Other programs for congestion mitigation, hydrogen-powered transportation, and transit developments all will potentially reduce greenhouse gases.

AGENCY FOR INTERNATIONAL DEVELOPMENT

Principal Areas of Focus

The Famine Early Warning System Network (FEWS NET) is an innovative application of science for supporting efforts to alleviate risks related to existing climate variability or potential climate change. Through FEWS NET, USAID is able to provide decisionmakers—both in the United States and in the developing world—with information designed to support policy and program interventions for effective and timely response to drought and food insecurity. FEWS NET historically focused its activities in 18 drought-prone countries across sub-Saharan Africa and, as of 2003, FEWS NET has expanded its coverage to include select countries in Central Asia and Latin America and the Caribbean. In addition to monitoring a wide variety of socioeconomic indicators to identify levels of food insecurity, FEWS NET monitors and analyzes remotely sensed data and ground-based meteorological, crop, and rangeland observations to track the progress of rainy seasons and crop production in semi-arid regions, in order to identify early indications of reduced food availability and access.

Program Highlights for FY 2008

In FY 2008, FEWS NET will continue to provide seasonal monitoring in relationship to analyses of food insecurity conditions in Africa and Central America, as well as in Haiti and Afghanistan. A major element of this work has been to strengthen information networks that collect and analyze data to reveal intra- and interannual climate variability trends as they relate to possible longer term climate variability and change.

ENVIRONMENTAL PROTECTION AGENCY

Principal Areas of Focus

EPA's Global Change Research Program is stakeholder-oriented, with primary emphasis on assessing the potential consequences of global change (particularly climate variability and change) on air quality, water quality, aquatic ecosystems, human health, and socioeconomic systems in the United States. EPA uses the results of these studies to investigate adaptation options to improve society's ability to effectively respond to the risks and opportunities presented by global change, and to develop decision-support tools for resource managers coping with a changing climate. The program is multidisciplinary and emphasizes the integration of the concepts, methods, and results of the physical, biological, and social sciences into decision-support frameworks. This work is consistent with and closely coordinated with the 2003 *CCSP Strategic Plan*.

The program uses a place-based approach because the impacts of global change and their solutions are often unique to a location (e.g., a watershed). Partnerships are established with locally based decisionmakers to ensure that the program is responsive to their unique scientific information needs and the socioeconomic realities at their locales.

The planning and implementation of EPA's program is integrated by the CCSP with other participating Federal departments and agencies to reduce overlaps, identify and fill programmatic gaps, and add integrative value to products and deliverables produced under the CCSP's auspices. EPA coordinates with other CCSP agencies to develop and provide timely, useful, and scientifically sound information to decisionmakers. This includes support for the production of CCSP synthesis and assessment products called for in the *CCSP Strategic Plan*, and the development of decision-support tools for resource managers and decisionmakers. Also, as called for by the National Research Council in 2001, EPA supports and fosters projects that link the producers and users of knowledge in a dialog that builds a mutual understanding of what is needed, what can credibly be said, and how it can be said in a way that maintains scientific credibility.

EPA's program has two major areas of emphasis: air quality and water quality/aquatic ecosystems. The program also evaluates the human health consequences of the changes in air quality, water quality, and aquatic ecosystems.

Air Quality

Studies are underway that examine the potential consequences of global change on air quality in the United States. The long-term goal of this focus area is to provide the approaches, methods, and models to quantitatively evaluate the effects of global change on air quality, and to identify technology advancements and adaptive responses and quantify their effect on air quality.

Water Quality/Aquatic Ecosystems

EPA's mission is to protect human health and safeguard the natural environment. EPA provides environmental protection that contributes to making communities and ecosystems diverse, sustainable, and economically productive. Consistent with this goal, EPA's Global Change Research Program is assessing the impacts of global change on water quality and aquatic ecosystems in the United States.

Water quality is affected by changes in runoff following changes in precipitation and evapotranspiration and/or changes in land use. The program is investigating the possible impacts of global change (climate and land-use change) on water quality using a watershed approach. A major focus is on studying the sensitivity to climate change of goals articulated in the Clean Water Act and the Safe Drinking Water Act, and the opportunities available within the provisions of these Acts to address anticipated impacts.

The program also has planned research activities that evaluate the effects of global change on aquatic ecosystems (which may include lakes, rivers, and streams; wetlands; and estuaries and coastal ecosystems), invasive nonindigenous species, and ecosystem services. EPA's investigations of the effects of global change on aquatic ecosystems uses as input the research being done by other CCSP agencies on marine and terrestrial ecosystems. Therefore, EPA's ability to successfully complete its assessments depends crucially upon the ability of other CCSP agencies to complete their related research activities.

Human Health

Since health is affected by a variety of social, economic, political, environmental, and technological factors, investigating the health impacts of global change is a complex challenge. As a result, health studies in EPA's Global Change Research Program go beyond basic epidemiological research to develop integrated health evaluation frameworks that consider the effects of multiple stresses, their interactions, and human adaptive responses. Along with health sector studies conducted in conjunction with other CCSP agencies, there are research activities focused on the possible consequences of global change on weather-related morbidity and vector- and water-borne diseases. In addition, the results from the program's air quality studies and water quality studies will be used to evaluate health consequences.

Intramural and extramural research contribute to all of EPA's investigations. In an attempt to capitalize on expertise in the academic community, a significant portion of the program's resources is dedicated to extramural research grants administered through the STAR (Science to Achieve Results) program. The STAR program focuses on science to support investigations of the consequences of global change for air quality, ecosystems, and human health in the United States. EPA will continue to coordinate closely with other CCSP agencies to identify the specific topics that should be emphasized within the STAR program.

Program Evaluation

The EPA Global Change Research Program is evaluated through extensive review by EPA's independent Board of Scientific Counselors (BOSC). A review in 2006 by the BOSC concluded that the program has conducted the "right work" and done it "well." The program "has provided substantial benefits to the Nation" and "is on course to make significant further contributions to societal outcomes by informing and facilitating decisions by the public and private sector actors who must consider the prospects of global change."

Program Highlights for FY 2008

EPA will continue to make significant contributions to the ongoing research activities of CCSP, and provide timely and useful information to resource managers coping with a changing climate. EPA-sponsored investigations will continue to be conducted through public-private partnerships that actively engage researchers from the academic community, decisionmakers, resource managers, and other

affected stakeholders. Highlights of specific activities that will be undertaken or completed by EPA in FY 2008 follow:

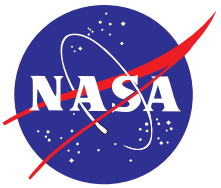
- Complete the three CCSP synthesis and assessment products for which EPA is the Lead Agency, and support production and completion of eight others.
- Initiate the second phase of EPA's quantitative assessment of the effects of global change on air quality in the United States.
- Initiate an assessment of the impacts of climate change on water quality in the United States in support of EPA's statutory requirements under the Clean Water Act and the Safe Drinking Water Act.
- Release an assessment of the effects of climate change and interacting stressors on the establishment and expansion of aquatic invasive species, and the implications for resource management.
- Complete an assessment of the consequences of global change for water quality related to biocritera.
- Release national maps depicting land-use scenarios for the conterminous United States consistent with IPCC emissions storylines, for use in assessments of where climate-land use interactions may exacerbate impacts or create adaptation opportunities; also release an online ArcGIS tool that can be used to generate additional land-use scenarios with customized inputs.
- Release a new online Climate Assessment Tool that provides resource managers with the ability to assess and manage impacts of climate change on sediment loadings to streams (e.g., through the use of riparian buffer zones).
- Co-sponsor with NOAA a study by the National Research Council of strategies and methods for climate-related decision support.
- Issue a joint Request for Proposals with the Centers for Disease Control and Prevention (CDC) focusing on the potential impacts of climate change on human health in the United States.

Related Research

In addition to focused CCSP activities, EPA conducts research that contributes to the characterization and understanding of risks to ecosystems and to human health. The ecosystems-based research is designed to understand and predict ecosystem exposure, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors (e.g., invasive species, genetically altered organisms) at multiple scales of biological organization and geographic scales. The research in human health is oriented toward assessing the cumulative health risks to humans (e.g., cancer, reproductive, cardiovascular)—including high-risk subpopulations (e.g., children)—from chemical stressors emanating from multiple sources. Both of these major research areas will be affected by and are inextricably interrelated with climate change.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Principal Areas of Focus



The National Aeronautics and Space Administration conducts a program of research to advance knowledge on the most important questions in Earth science through space-based observation and development and deployment of enabling technologies, as authorized in the NASA Authorization Act of 2005 and in the Presidential National Space Policy of 2006. NASA's end-to-end program of calibrated and validated observations, scientific and technological research and modeling, and application of this knowledge for societal benefits encompasses all themes of the *Strategic Plan for the U.S. Climate Change Science Program*. NASA's FY 2008 investment in the 13-agency Climate Change Science Program is 56% of the total amount of the President's FY 2008 Budget Request for CCSP. In addition, NASA contributes substantially to other interagency initiatives complementary with CCSP, including the *U.S. Ocean Action Plan* and the Strategic Plan for the *U.S. Integrated Earth Observation System*.

NASA continues to fulfill the National Research Council vision for U.S. leadership in interdisciplinary Earth science research to understand the complexity of the changing environment, its interaction with life, and how human activities affects the environment, and, in association with national and international agencies, to apply this understanding for the well-being of society (described in the January 15, 2007, report entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, known as the NRC Decadal Survey).

NASA climate science and technology encompass Earth's global atmosphere from the surface of the land and sea to the top of the stratosphere; the global oceans including sea ice; all land surfaces including snow and ice; the solid Earth beneath the ocean; the ecosystems in the air, oceans, and land; and all the interactions between the atmosphere, oceans, land, snow, ice, and associated ecology, including humans. NASA studies the Sun and the interaction of its radiation with the Earth's upper atmosphere, not only through its Earth Science program as reported here, but through its Heliophysics Program, which emphasizes solar physics and the mechanisms of the Sun-Earth connection.

NASA pioneered the interdisciplinary field of global integrated Earth system science, which explores the interactions among land, oceans, atmosphere, ice, and life. To study the components of the global integrated Earth system and interactions between components, NASA developed and deployed a constellation of satellites. The following NASA satellites are currently operating: ACRIMSAT, Aqua, Aura, CALIPSO, CloudSat, EO, GRACE, ICESat, Jason, Landsat-7, QuikSCAT, SORCE, Terra, and TRMM. NASA deploys aircraft- and surface-based instruments for calibration, validation, and increased level of interpretation of satellite data that are required for development of climate-quality satellite measurements. To accomplish its mission on understanding the global integrated Earth system, NASA possesses state-of-the-art computing capability and capacity for extensive global integrated Earth system modeling and maintains the world's largest data and information system for collecting, processing, archiving, and distributing scientific data.

NASA addresses the overarching climate question "How is the Earth changing, and what are the consequences for life on Earth?" Five subordinate questions describe both the NASA and CCSP approach to understanding the global integrated Earth system: How is the global Earth system changing;

what are the primary causes of change in the Earth system; how does the Earth system respond to natural and human-induced change; what are the consequences of change in the Earth system for human civilization; and how well can we predict future changes in the Earth system?

To understand the global integrated Earth system, NASA, within the Earth Science Division Research Program, organized science focus areas, some of which are aligned with CCSP research elements. Four NASA science focus areas—Atmospheric Composition, Climate Variability and Change, Global Water and Energy Cycle, and Carbon Cycle and Ecosystems—are aligned directly with CCSP research elements. The NASA Earth Science Division Applied Sciences Program has many features that are aligned with the CCSP research element Human Contributions and Resources. Weather and Earth Surface and Interior are additional NASA science focus areas.

CCSP RESEARCH ELEMENTS	NASA GLOBAL INTEGRATED EARTH SYSTEM SCIENCE FOCUS AREAS
Atmospheric Composition	Atmospheric Composition
Climate Variability and Change	Climate Variability and Change
Global Water Cycle	Global Water and Energy Cycle
Land-Use/Land-Cover Change Global Carbon Cycle Ecosystems	Carbon Cycle and Ecosystems
Human Contributions and Responses	Applied Sciences

Program Highlights for FY 2008

In the summer of 2007, NASA held workshops to initiate planning of four new satellite missions that were recommended by the NRC Decadal Survey. These missions would measure spectrally resolved incident solar radiation and outgoing Earth radiation at the top of the atmosphere (CLARREO), land surface and ice deformations and vegetation structure (DESDynI), ice sheet structure (ICESat-II), and soil moisture and freeze/thaw conditions (SMAP). These missions would contribute to FY 2008 CCSP interagency implementation priorities, which have multi-year lifetimes: aerosol forcing, clouds, and radiation (CLARREO); abrupt climate change (DESDynI and ICESat-II); carbon cycle, ecosystem productivity, and land cover (DESDynI); and water cycle and drought (SMAP). In FY 2008, NASA intends to continue evaluating technical and scientific aspects of satellite missions recommended by the NRC Decadal Survey.

NASA will make significant progress in FY 2008 to expand scientific knowledge in each of the eight CCSP interagency implementation priorities. These contributions draw from NASA's capabilities in obtaining global space-based observations, and using them, together with ground- and aircraft-based observations, to improve knowledge of Earth system processes and to improve predictive capability for addressing the future evolution of the Earth system. Some examples of NASA's activities in each high-priority CCSP research area follow.

Integrated Earth System Analysis Capability

NASA's Modern Era Retrospective-Analysis for Research and Applications (MERRA) project focuses on data assimilation in implementing a national capability for studies of the global integrated Earth system. MERRA utilizes the version 5 Goddard (Space Flight Center) Earth Observing System (GEOS-5) atmospheric general circulation model with Gridpoint Statistical Interpolation (GSI) assimilation of satellite and *in situ* observations to produce global analyses of the atmosphere during the satellite era 1979 to present. Variability and predictability of the hydrological cycle will be emphasized. An External Users Group participating in MERRA's development showed that assimilating rain rates improved precipitation analyses and estimates of the outgoing longwave radiation. In FY 2008, MERRA will be operational and will provide the highest quality atmospheric reanalysis for the satellite era.

Integration of Water Cycle Observations, Research, and Modeling

The NASA Energy- and Water-cycle Study (NEWS) program integrates observations and models to close the water cycle budget for limited regions. NEWS is expected to provide a comprehensive depiction of regional water stocks and fluxes over the globe. GRACE data will be used to estimate monthly water volume variations in ocean, ice, land, and atmosphere reservoirs, including distribution of source and sink regions of freshwater between storage reservoirs. TRMM and other measurements recorded over the United States will be analyzed to test a hypothesis that aerosols can reduce the orographic enhancement of precipitation downwind of urban areas. The fundamental relationship between global hydrological cycle and Earth's radiative energy balance will be studied with data from the A-Train (MODIS/Aqua, AMSR/Aqua, Cloudsat). NEWS data sets of all three phases of water—vapor, ice, liquid—will explore the coupled dynamics and thermodynamics of tropical intraseasonal fluctuations, which degrade the predictability of tropical weather. The strong linkage between MERRA and NEWS will improve understanding of the causes and predictability of droughts, including the impact of global warming on drought.

Carbon Cycle Research Integration

NASA will support scientific studies in FY 2008 that provide unique information to characterize and quantify carbon stocks and fluxes for North America and adjacent oceans. Landsat data, available since 1972, will be utilized in estimating sources and sinks of carbon in the continental United States over the past 3 decades. In the North American boreal region where black spruce forests are a major carbon reservoir, trajectories of post-fire succession will be determined with MODIS/Aqua, MODIS/Terra, and Landsat data. NASA will test a new technique to measure methane, which has a global warming potential more than twenty times that of carbon dioxide on a per molecule basis. The timing and duration of surface and soil freeze-thaw states, which impact emissions and uptake of atmospheric carbon, will be determined over North America with QuikSCAT data. The hypothesis that the coastal ocean is a sink for atmospheric carbon dioxide will be tested with SeaWiFS, MODIS/Aqua, and MODIS/Terra data.

Understanding Aerosol Forcing and Interactions with Clouds and non-CO_2 Gases

NASA's Tropical Composition, Cloud and Climate Coupling (TC4) project involved three aircraft (ER-2, DC-8, and WB-57), seven satellites [Aqua, Aura, CALIPSO, CloudSat, PARASOL (non-NASA), Terra, and TRMM], and high-altitude balloons during a 17 July - 8 August 2007 campaign focusing on an area near Costa Rica. TC4 involved more than 400 scientists, students, and support staff. In addition to calibration and validation of satellite instruments, TC4 examined the production and aging of clouds and the transport of chemicals in the vicinity of the tropical tropopause transition layer at about

12- to 17-km altitude where vigorous vertical motion in the atmosphere over the ocean carries gases and aerosols up from the troposphere. High-resolution balloon observations of ozone and water reached the middle stratosphere. NASA's aircraft instruments measured radiation, aerosols, and a wide range of chemical constituents, including total water and water vapor that influence Earth's climate. Water vapor isotopic abundance measurements will be used to understand vertical transport across the tropopause. In FY 2008, the large volume of data will be processed, analyzed, and synthesized by more than 50 NASA-supported research groups. Identifying the key processes in the tropical tropopause-stratosphere region is important for progress on global climate change, stratospheric ozone depletion, and global tropospheric chemistry.

Abrupt Changes in a Warming Climate

NASA will continue its scientific leadership on studies of rapid or abrupt climate change through its research on Greenland and Antarctica ice sheets, Arctic Ocean ice coverage, global sea level, Atlantic Ocean meridional circulation, and global integrated Earth system modeling, which introduced the concept of "climate tipping point" with regard to a dangerous level of atmospheric greenhouse gas concentration. Measurements from GRACE and ICESat showed that the total volume of the world's ice sheets are getting smaller through melting, with a consequence of increasing sea level evidenced by TOPEX/Poseidon and Jason observations, which indicated global annual mean sea level was rising faster than that predicted by the Intergovernmental Panel on Climate Change. In FY 2008, the first-ever measurement of the total discharge of ice from the grounded Antarctic Ice Sheet will be estimated with ICESat and Landsat data. Greenland ice sheet thicknesses recorded in September 2007 with a high-frequency radar instrument on a NASA aircraft will be analyzed in FY2008. The dramatic decline of Artic Ocean ice coverage over the past 25 years, primarily in summer months and also during winter, dictates the need for improved knowledge of Pan-Arctic sea ice export and efficacy of Arctic Ocean sea ice models, which NASA will emphasize in FY2008. Preparations will continue for the launch in 2009 of the sea surface salinity satellite mission Aquarius, which will contribute substantially to predictions of future behavior of the Atlantic meridional overturning circulation, a feature associated with abrupt climate change.

Impacts of Climate Variability and Change on Ecosystem Productivity and Biodiversity

NASA will complete a number of studies in FY 2008 analyzing the vulnerability of biodiversity to changing climates in various ecosystems, including coastal and high-elevation ecosystems. Examples of studies include the impact of El Niño on fisheries off California, ocean upwelling dynamics in the Galapagos Marine Reserve, intertidal biogeography, biodiversity changes with mountain altitude in Ecuador, impacts of land-cover changes on montane cloud forests in Costa Rica, estimation of the number of tree species in ecoregions of the continental United States, and biophysical and land-use controls on biodiversity in North America. These activities involve a wide range of satellite sensors, including MODIS/Aqua, MODIS/Terra, and ASTER/Terra.

Land Use and Land Cover Change and Climate Interactions

The Mid-Decadal Global Land Survey (MDGLS), a project of NASA and USGS, assembled a global 30-m spatial resolution land cover data set for 2004-2007 using Landsat-5, Landsat-7, ASTER/Terra, and EO measurements. In 2008, NASA will generate and distribute MDGLS data products for comparative studies on land-use and land-cover (LULC) change with similar data products developed for the 1970s, 1990s, and circa 2000. Additionally, in FY 2008, NASA will initiate five to seven scientific studies on the environmental, social, economic, and human health consequences of LULC

changes projected over the next 5-50 years. A subset of the NASA selected projects will support the Northern Eurasia Earth Science Partnership Initiative (NEESPI) and the Monsoon Asia Integrated Regional Study (MAIRS) on carbon and water cycle processes and land-cover changes including fires.

Coping With Drought Through Research and Regional Partnerships

NASA works with governmental organizations to infuse NASA observations and scientific research results into operational data products that benefit society. In FY 2008, NASA will continue its partnership with the Northern Colorado Water Conservation District and the Bureau of Reclamation in utilizing MODIS/Aqua, MODIS/Terra, ASTER/Terra, and Landsat-7 data to estimate weekly evapotranspiration for real-time water management applications. NASA is investigating potential improvement of the weekly NOAA-USDA Drought Monitor of intensity and extent of drought conditions over North America through a partnership with USGS and others working with NOAA and USDA to utilize MODIS/Aqua and MODIS/Terra data.

NATIONAL SCIENCE FOUNDATION

Principal Areas of Focus

NSF programs address global change issues through investments in challenging ideas, creative people, and effective tools. In particular, NSF global change research programs support research and related activities to advance the fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary activities and focus particularly on Earth system processes and the consequences of change. NSF programs facilitate data acquisition and information management activities necessary for fundamental research on global change, and promote the enhancement of models designed to improve understanding of Earth system processes and interactions, and to develop advanced analytic methods to facilitate basic research. NSF also supports fundamental research on the general processes used by organizations to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of varying environmental conditions. Through its investment, NSF contributes to CCSP by providing a comprehensive scientific foundation for many of the synthesis and assessment products identified in the *CCSP Strategic Plan*.

Program Highlights for FY 2008

Atmospheric Composition

NSF programs in tropospheric and stratospheric chemistry will continue to address the composition of the atmosphere and its relation to climate variability and change. Studies of the transformation and transport of gaseous constituents and aerosols provide insights into the radiative and cloud nucleating properties of the atmosphere. Studies of the global distributions of greenhouse gases and aerosols will provide input for future scenarios of radiative forcing.

Climate Variability and Change

NSF programs continue to emphasize climate variability and change as a major issue. This research element supports observational campaigns and numerous analytical and modeling activities. Ocean science efforts will focus on changes in ocean structure, circulation, and interactions with the atmosphere to improve current understanding of the processes and models that address future changes, particularly those that may happen abruptly. Studies of decadal variability and changes in the statistics of extreme weather events will be an area of emphasis in climate change research. The Community Climate System Model (CCSM) is being developed to improve model physics and parameterizations that will lead to more comprehensive models incorporating interactive chemistry and biology. It also is being tested in combination with an embedded, state-of-the-art, mesoscale model to carry out high-resolution decadal climate prediction. Studies of paleoclimatology will continue to be supported as a means to provide baseline data on natural climate variability from the past and from key climatic regions. These studies will improve understanding of the natural variability of the climate system and in particular will enable reconstructions and evaluations of past environmental change as inputs for model validations.

The Global Water Cycle

NSF supports a broad-based effort to understand all aspects of the global water cycle with continued emphasis on interdisciplinary research. Relevant programs will continue to explore ways to optimally and effectively utilize the wide range of hydrological data types—continuous and discrete time and

space information from a variety of platforms for research purposes. Information from process studies will be used to refine models through scaling and parameterizations of sub-grid processes, particularly the fluxes of water through the Earth system. Planning for and the initiation of several prototype hydrological observatories, both physical and virtual, are being carried out. Science and Technology Centers will continue to work with stakeholders responsible for water management and with educators to translate research advances into useful products, particularly exploring issues related to decisionmaking in the face of uncertainty as applied to the urbanizing and drought-prone Southwest. NSF's International Polar Year investments will emphasize ice sheet change as a contribution to understanding the global water cycle.

Land-Use and Land-Cover Change

Several NSF programs continue to address key aspects of land-use and land-cover change through studies in ecological rates of change and related species diversity; Arctic systems; temporal variability; water and energy influences on vegetative systems; and diverse human influences on land utilization.

Global Carbon Cycle

NSF supports a wide variety of carbon cycle research activities. Investigations examine a range of topics in terrestrial and marine ecosystems and their relations to the carbon cycle. Research in terrestrial settings will explore, for example, carbon storage, delivery of carbon by rivers, carbon fluxes from high-latitude soils, and carbon export from mountains and submarine groundwater discharge. In the oceans, air-sea gas exchange, remineralization of particles in the mesopelagic, and the upper ocean carbon budget will be addressed. Carbon cycle studies will integrate observational data into models to provide insights for understanding key aspects of the global carbon cycle.

Ecosystems

Several NSF programs address terrestrial and marine ecosystems through observational, experimental, modeling, and laboratory studies. The collection of information and knowledge of climate-ecosystem interactions in terrestrial, freshwater, and marine systems through the Long-Term Ecological Research (LTER) projects derives from the rich array of observation, monitoring, experimentation, and modeling throughout this networked research program. The Hawaii Ocean Times-Series (HOT) and Bermuda Atlantic Time Series (BATS) sites augment the LTER network in the central ocean gyre ecosystems. The Global Ocean Ecosystem Dynamics program will continue to study the impact of global ocean changes on marine ecosystems through specific synthesis activities focused on the North Atlantic, North Pacific, and Southern Ocean systems.

Human Contributions and Responses

NSF supports basic research on the processes through which people (individually, in groups, or through organizations) interact with natural environmental systems. Programs support projects that focus on decisionmaking under uncertainty associated with climate change. These projects are expected to produce new knowledge and tools that should facilitate improved decisionmaking by various stakeholder groups trying to deal with uncertainties associated with future climate variability and change.

International Research and Cooperation

The "International Polar Year 2007-2008" (IPY) will extend from March 2007 through March 2009. The President's Office of Science and Technology Policy designated NSF the lead Federal agency in organizing U.S. International Polar Year activities. NSF IPY activities will focus on improving understanding of

climate change in both polar regions and on linkages between polar and global systems. In addition, NSF, in cooperation with NASA and international partners, will focus on longer term sea-level changes associated with changes in the stability of the Greenland and Antarctic ice sheets.

Related Research

NSF will continue to support "contributing" research on broader topics that are closely related to global and climate change. These include, *inter alia*, studies of the atmosphere, ocean, land surface, ecosystems, paleoclimatology, and human dimensions—all of which add substantively to the specific programs supporting CCSP objectives. NSF has the computing infrastructure in place and under enhancement to enable more effective utilization of the research information. In addition, NSF supports projects that integrate research with education on global and climate change to demonstrate that scientific visualization—incorporated into inquiry-based learning—can enable students to develop an understanding of complex global change phenomena. Students address these issues by evaluating multimedia data at various spatial and temporal resolutions, reviewing scientific evidence, and considering social concerns that contribute to global and climate change debates.

SMITHSONIAN INSTITUTION

National Air and Space Museum (NASM)
National Museum of Natural History (NMNH)
National Zoological Park (NZP)
Smithsonian Astrophysical Observatory (SAO)
Smithsonian Environmental Research Center (SERC)
Smithsonian Tropical Research Institute (STRI)

Principal Areas of Focus

Within the Smithsonian Institution, global change research is conducted at the Smithsonian Astrophysical Observatory, the National Air and Space Museum, the Smithsonian Environmental Research Center, the National Museum of Natural History, the Smithsonian Tropical Research Institute, and the National Zoological Park. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on daily to decadal time scales, and defining longer term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The Smithsonian Institution program strives to improve knowledge of the natural processes involved in global climate change, to provide a long-term repository of climate-relevant research materials for present and future studies, and to bring this knowledge to various audiences, ranging from scholarly to the lay public. The unique contribution of the Smithsonian Institution is a long-term perspective—for example, undertaking investigations that may require extended study before producing useful results and conducting observations on sufficiently long (e.g., decadal) time scales to resolve human-caused modification of natural variability.

Program Highlights for FY 2008

Atmospheric Composition
At SERC, measurements will be made of spectral UV-B in Maryland (>25-year record), Florida, Arizona, and other sites in the United States. These data will be electronically disseminated to meet the needs for assessing the biological and chemical impact of varying ultraviolet radiation exposures.

Climate Variability and Change
Research at NASM will emphasize the use of remote-sensing data to improve theories of drought, sand mobility, soil stability, and climate change in the Mojave Desert and Simpson Desert, Australia. Studies at NMNH and STRI will focus on the paleoecology of climate change.

Terrestrial and Marine Ecosystems
Several Smithsonian programs will examine biological responses to global change. At SERC, research will be conducted on the responses of global ecosystems to increasing carbon dioxide concentrations (also a contribution to the Global Carbon Cycle program). This SERC program will also focus on invasive species, and solar UV-B. Biodiversity education and research will be performed at STRI, NMNH, and NZP. Tropical biodiversity research programs monitor global change effects through repeated sampling of flora and fauna in tropical forests, and identifying the physical and biological

processes of growth and decline of species. Other studies on ecosystem response to increasing habitat fragmentation will be conducted at NZP.

Human Dimensions of Global Change

The general public and research community will be informed of global change research conducted by Smithsonian and other CCSP agencies via exhibits. During FY 2008, an exhibition on soils developed by staff at NMNH and SERC will be displayed at NMNH. Part of the "Forces of Change" series, the exhibition will include soils' role as atmospheric sources and sinks. The new Ocean Hall (SI/NOAA joint collaboration) will address issues such as loss of sea ice habitat and coral reef ecosystems due to global warming and ocean acidification.

Related Research

Much of the global change research performed at the Smithsonian is not supported by direct Federal appropriation (i.e., CCSP cross-cut funding) and instead is supported by other public and private sources (including other CCSP-participating agencies). These projects are nonetheless organized around the CCSP program elements, thus amplifying the scope and impact of research supported directly by CCSP. At SAO, there are extensive measurement programs for stratospheric and tropospheric composition. These include pollution measurement from space and its eventual development into continuous global monitoring. This work contributes to global climate observations, enhances climate modeling systems, quantifies greenhouse gas sources and sinks, and reduces scientific uncertainties of aerosol effects. There are continuing studies on solar activity and its relationship to climate. SERC and STRI receive agency support via competitive grants programs to perform studies of ecosystem responses to increased carbon dioxide, UV-B, and invasive species. Other contributing activities include research conducted by several units within the Smithsonian in a variety of habitats concerning natural and human-induced variations in species, populations-communities, and ecosystems. These studies help clarify the relative importance of global change effects as one of several agents of ecological change. Studies of environmental change over long time periods are aided by the Institution's collections. Used by researchers around the world, these materials provide raw data for evaluating changes in the physical and biological environment that occurred before human influences.

APPENDIX B
CLIMATE CHANGE SCIENCE PROGRAM
FY 2008 BUDGET TABLES

APPENDIX B

CLIMATE CHANGE SCIENCE PROGRAM FY 2008 BUDGET TABLES

The Climate Change Science Program (CCSP) integrates federally supported research on global change and climate change, as conducted by 13 U.S. Government departments and agencies:

- Department of Agriculture (USDA)
- Department of Commerce (DOC)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior (DOI)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

The CCSP incorporates and integrates the U.S. Global Change Research Program (USGCRP) with the Administration's U.S. Climate Change Research Initiative (CCRI). CCSP budget requests are coordinated through interagency research working groups and other mechanisms, but ultimate budget accountability resides with the participating departments and agencies. As a result of its interagency composition, activities of CCSP participating agencies are funded by Congress through nine of the 13 annual Appropriations bills.

The following tables summarize the CCSP budget:

- Tables 1 and 2 show the CCSP FY 2006-2008 budget aligned by CCSP goal.
- Table 3 shows the CCSP FY 2006-2008 budget by agency, with USGCRP and CCRI budgets listed separately and also combined in a single CCSP total.
- Table 4 shows the USGCRP FY 2006-2008 budget by CCSP research element.
- Table 5 shows the FY 2006-2008 CCRI budget.
- Subsequent tables show, for each CCSP participating agency, the FY 2006-2008 budget for both USGCRP and CCRI activities.

TABLE 1. FY 2006–2008 CLIMATE CHANGE SCIENCE PROGRAM BUDGET BY GOAL AND FOCUS AREA

Focus Area	Description (from *CCSP Strategic Plan*)[1]	Budgets ($M)[2] FY 2006	FY 2007 Estimate	FY 2008 Request	Agencies
Goal 1	**Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and changes**				
Focus 1.1	Better understand natural long-term cycles in climate [e.g., Pacific Decadal Variability (PDV), North Atlantic Oscillation (NAO)]	37.8	39.7	45.3	DOC, DOE, DOI, NASA, NSF
Focus 1.2	Improve and harness the capability to forecast El Niño-La Niña and other seasonal-to-interannual cycles of variability	38.5	37.9	38.1	DOC, DOE, DOI, NASA, NSF
Focus 1.3	Sharpen understanding of climate extremes through improved observations, analysis, and modeling, and determine whether any changes in their frequency or intensity lie outside the range of natural variability	38.9	36.9	37.4	DOC, DOE, DOI, NASA, NSF
Focus 1.4	Increase confidence in the understanding of how and why climate has changed	39.9	40.8	41.4	DOE, DOI, NASA, NSF, SI
Focus 1.5	Expand observations and data/information system capabilities	170.0	170.6	158.1	DOC, DOE, DOI, NASA, NSF, SI
GOAL 1 TOTAL		**325.1**	**325.9**	**320.3**	
Goal 2	**Improve quantification of the forces bringing about changes in the Earth's climate and related systems**				
Focus 2.1	Reduce uncertainties about the sources and sinks of greenhouse gases, emissions of aerosols and their precursors, and their climate effects	100.3	96.3	101.8	DOC, DOE, DOT, NASA, NSF
Focus 2.2	Monitor the recovery of the ozone layer and improve the understanding of the interactions of climate change, ozone depletion, tropospheric pollution, and other atmospheric issues	32.0	29.7	28.4	USDA, DOE, NASA
Focus 2.3	Increase knowledge of the interactions among emissions, long-range atmospheric transport, and transformations of atmospheric pollutants, and their response to air quality management strategies	40.1	40.4	40.4	NASA, NSF

[1] See Chapter 2 of the *Strategic Plan for the U.S. Climate Change Science Program* for a detailed discussion.
[2] Any minor discrepancies within this table and between this table and others are due to rounding.

TABLE 1 (CONTINUED)

Focus Area	Description (from *CCSP Strategic Plan*)[1]	Budgets ($M)[2] FY 2006	FY 2007 Estimate	FY 2008 Request	Agencies
Goal 2 (continued)					
Focus 2.4	Develop information on the carbon cycle, land cover and use, and biological/ecological processes by helping to quantify net emissions of carbon dioxide, methane, and other greenhouse gases, thereby improving the evaluation of carbon sequestration strategies and alternative response options	130.2	127.0	128.4	USDA, DOC, DOE, DOI, NASA, NSF, SI
Focus 2.5	Improve capabilities to develop and apply emissions and related scenarios for conducting "If…, then…" analyses in cooperation with CCTP	3.0	3.0	3.0	DOE
GOAL 2 TOTAL		**305.6**	**296.4**	**302.0**	
Goal 3	**Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future**				
Focus 3.1	Improve characterization of the circulation of the atmosphere and oceans and their interactions through fluxes of energy and materials	43.1	42.2	42.4	DOC, DOE, NASA, NSF
Focus 3.2	Improve understanding of key "feedbacks" including changes in the amount and distribution of water vapor, extent of ice and the Earth's reflectivity, cloud properties, and biological and ecological systems	80.1	75.4	75.6	DOE, DOI, NASA, NSF
Focus 3.3	Increase understanding of the conditions that could give rise to events such as rapid changes in ocean circulation due to changes in temperature and salinity gradients	6.4	6.2	6.1	NASA, NSF
Focus 3.4	Accelerate incorporation of improved knowledge of processes and feedbacks into climate models to reduce uncertainty in projections of climate sensitivity, changes in climate, and related conditions such as sea level	85.3	86.1	93.7	DOC, DOE, NASA, NSF
Focus 3.5	Improve national capacity to develop and apply climate models	38.9	35.5	44.8	DOC, DOE, NASA, NSF
GOAL 3 TOTAL		**253.8**	**245.4**	**262.6**	

TABLE 1 (CONTINUED)

Focus Area	Description (from *CCSP Strategic Plan*)[1]	Budgets ($M)[2] FY 2006	FY 2007 Estimate	FY 2008 Request	Agencies
Goal 4	**Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes**				
Focus 4.1	Improve knowledge of the sensitivity of ecosystems and economic sectors to global climate variability and change	65.1	62.3	63.8	USDA, DOE, DOI, EPA, NASA, NSF, SI
Focus 4.2	Identify and provide scientific inputs for evaluating adaptation options, in cooperation with mission-oriented agencies and other resource managers	56.4	56.3	55.5	HHS, EPA, NSF
Focus 4.3	Improve understanding of how changes in ecosystems (including managed ecosystems such as croplands) and human infrastructure interact over long time periods	48.3	42.5	37.5	USDA, DOC, DOE, NASA, NSF, SI
GOAL 4 TOTAL		**169.8**	**161.1**	**156.8**	
Goal 5	**Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change**				
Focus 5.1	Support informed public discussion of issues of particular importance to U.S. decisions by conducting research and providing scientific synthesis and assessment reports	70.6	60.0	61.6	USDA, DOE, DOI, DOT, EPA, NASA, NSF, SI
Focus 5.2	Support adaptive management and planning for resources and physical infrastructure sensitive to climate variability and change; build new partnerships with public and private sector entities that can benefit both research and decisionmaking	63.5	66.9	66.1	USDA, DOC, DOI, USAID, EPA, NASA, NSF
Focus 5.3	Support policymaking by conducting comparative analyses and evaluations of the socioeconomic and environmental consequences of response options	9.7	8.3	8.4	USDA, DOI, NASA, NSF, SI
GOAL 5 TOTAL		**143.8**	**135.2**	**136.1**	
CCSP PROGRAM TOTAL		**1,198.0**	**1,164.0**	**1,177.8**	

TABLE 2. FY 2006–2008 CLIMATE CHANGE SCIENCE PROGRAM BUDGET BY GOAL AND PARTICIPATING AGENCY/DEPARTMENT

[DISCRETIONARY BUDGET AUTHORITY IN $M]

	Research													
	USDA	DOC	DOE	HHS	DOI	DOT	USAID	EPA	NASA	NSF	SI	Res Subtotal	Obs[1] Subtotal	TOTAL
FY 2008 Request														
Goal 1	0.0	138.3	48.6	0.0	12.6	0.0	0.0	0.0	76.6	43.1	1.1	320.3	344.0	664.3
Goal 2	18.3	43.4	32.4	0.0	2.9	0.5	0.0	0.0	143.5	60.6	0.4	302.0	118.2	420.2
Goal 3	0.0	47.4	32.2	0.0	1.3	0.0	0.0	0.0	124.1	57.6	0.0	262.6	158.0	420.6
Goal 4	16.4	2.0	15.4	49.0	7.1	0.0	0.0	4.9	21.0	37.8	3.2	156.8	38.2	195.0
Goal 5	22.8	13.7	1.0	0.0	2.5	0.7	13.0	12.0	60.1	9.3	1.0	136.1	0.0	136.1
TOTAL	**57.5**	**244.8**	**129.6**	**49.0**	**26.4**	**1.2**	**13.0**	**16.9**	**425.3**	**208.4**	**5.7**	**1,177.8**	**658.4**	**1,836.2**
FY 2007 Estimate														
Goal 1	0.0	139.7	48.6	0.0	12.6	0.0	0.0	0.0	81.7	42.2	1.1	325.9	294.5	620.4
Goal 2	18.5	37.6	32.4	0.0	2.9	0.3	0.0	0.0	144.1	60.2	0.4	296.4	168.3	464.7
Goal 3	0.0	42.1	25.0	0.0	1.3	0.0	0.0	0.0	120.9	56.1	0.0	245.4	159.7	405.1
Goal 4	16.4	3.8	19.2	50.0	7.1	0.0	0.0	4.3	19.6	37.5	3.2	161.1	36.5	197.6
Goal 5	24.5	12.5	1.0	0.0	2.5	0.7	14.0	11.9	57.8	9.3	1.0	135.2	0.0	135.2
TOTAL	**59.4**	**235.7**	**126.2**	**50.0**	**26.4**	**1.0**	**14.0**	**16.2**	**424.1**	**205.3**	**5.7**	**1,164.0**	**659.0**	**1,823.0**
FY 2006														
Goal 1	0.0	141.1	48.3	0.0	12.6	0.0	0.0	0.8	81.6	39.6	1.1	325.1	196.1	521.2
Goal 2	18.4	38.0	32.4	0.0	2.8	0.3	0.0	0.0	156.0	57.3	0.4	305.6	130.1	435.7
Goal 3	0.0	43.2	25.6	0.0	2.1	0.0	0.0	0.0	129.3	53.6	0.0	253.8	136.0	389.8
Goal 4	17.1	4.5	22.9	50.0	6.9	0.0	0.0	6.5	21.6	37.1	3.2	169.8	30.7	200.5
Goal 5	25.6	8.2	1.0	0.0	2.4	0.6	13.0	11.3	71.4	9.3	1.0	143.8	0.0	143.8
TOTAL	**61.0**	**235.0**	**130.2**	**50.0**	**26.8**	**0.9**	**13.0**	**18.6**	**459.9**	**196.9**	**5.7**	**1,198.0**	**492.9**	**1,690.9**

[1]NASA observing systems.
Note: Any minor discrepancies within this table and between this table and others are due to rounding.

TABLE 3. CLIMATE CHANGE SCIENCE PROGRAM: FY 2006–2008 BUDGET BY AGENCY

[DISCRETIONARY BUDGET AUTHORITY IN $M]

Agency	FY 2006			FY 2007 Estimate			FY 2008 Request		
	USGCRP	CCRI	CCSP	USGCRP	CCRI	CCSP	USGCRP	CCRI	CCSP
USDA	53	8	61	50	8	58	48	8	56
DOC[1,2]	201	34	235	190	46	236	199	46	245
DOE	102	28	130	103	24	127	106	24	130
HHS	50	0	50	50	0	50	49	0	49
DOI	27	0	27	26	0	26	27	0	27
DOT	0	1	1	1	0	1	0	1	1
USAID	0	13	13	0	14	14	0	13	13
EPA[3]	19	0	19	16	0	16	17	0	17
NASA[4,5]	421	38	460	389	35	424	390	35	425
NSF	172	25	197	180	25	205	183	25	208
SI	6	0	6	6	0	6	6	0	6
Scientific Research Total	**1,052**	**147**	**1,199**	**1,011**	**152**	**1,163**	**1,025**	**152**	**1,178**
NASA Space-Based Observations	**436**	**57**	**493**	**566**	**94**	**659**	**618**	**40**	**659**
CCSP Total[6,7]	**1,487**	**203**	**1,691**	**1,576**	**246**	**1,822**			
President's Request							**1,644**	**193**	**1,836**

Notes:

1 Starting in FY 2006, funding to NOAA's laboratories is included in the CCSP budget cross-cut. This is a result of the evolution of NOAA's role in CCSP.

2 For FY 2008, NOAA made a decision to report activities for the NOAA climate strategic goal, as defined in the NOAA Strategic Plan (2005), to ensure consistent reporting and to provide the most accurate picture of its climate funding to date. The climate goal includes both research and operations funding under the following offices: Office of Oceanic and Atmospheric Research, National Marine Fisheries Service, the National Weather Service, and the National Environmental Satellite, Data, and Information Service.

3 Entries given in FY 2006 and FY 2007 for EPA are "enacted" budgetary amounts.

4 NASA funding levels presented in this table do not reflect full-cost accounting (Corporate General and Administrative and Institutional Investment funding has been removed).

5 NASA has revised the set of projects it counts as supporting CCSP goals. The funding levels presented here do not include the Ground Network and Research Range assets or Congressional interest items, but include activities not previously counted, such as the NPOESS Preparatory Project, portions (33%) of the Landsat Data Continuity Mission, and the Gravity Recovery and Climate Experiment, as well as portions of the High-End Computing and Scientific Computing projects.

6 Operational space-based, surface, and *in situ* observing systems and programs are not included in the CCSP budget cross-cut, but contribute to achieving CCSP goals. Because DOD research activities are conducted for defense-related missions, they are not included in the CCSP budget cross-cut; however, related DOD research contributes to CCSP goals.

7 Due to recent changes in CCSP/CCRI activities and priorities, additional ongoing activities in the Democracy, Conflict, and Humanitarian Assistance program are reported under CCSP and CCRI beginning in FY 2006.

* Any minor discrepancies within this table and between this table and others are due to rounding.

TABLE 4. CLIMATE CHANGE SCIENCE PROGRAM: FY 2006-2008 USGCRP SCIENTIFIC RESEARCH BUDGET BY CCSP RESEARCH ELEMENT

[DISCRETIONARY BUDGET AUTHORITY IN $M]

Agency	Atmospheric Composition	Climate Variability	Carbon Cycle	Water Cycle	Ecosystems	Land Use	Human Contributions[1]	TOTAL
FY 2008 USGCRP Research Elements								
USDA	18.3	–	11.2	4.9	14.9	0.1	–	49.4
DOC	26.2	148.9	5.1	9.9	2.0	–	6.9	199.0
DOE	12.6	64.6	10.5	–	13.2	–	5.1	106.0
HHS	–	–	–	–	–	–	49.0	49.0
DOI	1.8	5.4	1.2	4.3	5.9	7.3	0.5	26.4
DOT	0.5	–	–	–	–	–	–	0.5
EPA	6.2	–	–	–	4.9	–	5.8	16.9
NASA	77.0	83.4	48.9	92.9	40.1	19.7	28.1	390.1
NSF	20.7	79.4	31.2	17.4	20.5	2.8	11.2	183.2
SI	–	1.3	0.3	–	3.3	0.8	–	5.7
TOTAL	**163.3**	**383.0**	**108.4**	**129.4**	**104.8**	**30.7**	**106.6**	**1,026.2**
FY 2007 USGCRP Research Elements								
USDA	19.6	–	10.2	5.3	15.0	1.3	–	51.4
DOC	21.0	146.5	4.9	9.5	1.5	–	6.6	190.0
DOE	12.6	57.2	10.5	–	17.0	–	5.1	102.4
HHS	–	–	–	–	–	–	50.0	50.0
DOI	1.8	5.4	1.2	4.3	5.9	7.3	0.5	26.4
DOT	0.3	–	–	–	–	–	–	0.3
EPA[2]	5.9	–	–	–	4.3	–	6.0	16.2
NASA	79.9	80.6	46.2	93.9	39.7	20.3	28.4	389.0
NSF	20.7	78.4	30.2	16.4	20.5	2.8	11.2	180.2
SI	–	1.3	0.3	–	3.3	0.8	–	5.7
TOTAL	**161.8**	**369.4**	**103.5**	**129.4**	**107.2**	**32.5**	**107.8**	**1,011.6**
FY 2006 USGCRP Research Elements								
USDA	20.7	–	10.3	5.4	15.7	1.3	–	53.4
DOC	21.8	155.6	5.2	9.9	1.5	–	6.9	200.9
DOE	12.8	55.5	10.1	–	20.5	–	3.5	102.4
HHS	–	–	–	–	–	–	50.0	50.0
DOI	1.8	5.0	1.3	4.3	6.2	7.7	0.5	26.8
DOT	0.3	–	–	–	–	–	–	0.3
EPA[2]	7.2	–	–	–	6.5	–	4.9	18.6
NASA	85.1	85.4	50.6	94.4	45.3	22.0	38.8	421.6
NSF	19.5	74.3	25.0	18.0	21.1	2.8	11.2	171.9
SI	–	1.3	0.3	–	3.3	0.8	–	5.7
TOTAL	**169.2**	**377.1**	**102.8**	**132.0**	**120.1**	**34.6**	**115.8**	**1,051.6**

[1] Prior to FY 2007, NASA linked the Applied Sciences and the Education and Outreach programs to USGCRP Focus Areas, but not to CCSP research elements; the current table identifies these programs as contributing to the CCSP Human Contributions and Responses element for the three fiscal years addressed.

[2] Entries given in FY 2006 and FY 2007 for EPA are "enacted" budgetary amounts.

Note: Any minor discrepancies within this table and between this table and others are due to rounding.

TABLE 5. FY 2006-2008 BUDGET FOR THE CLIMATE CHANGE RESEARCH INITIATIVE (CCRI)

Agency	Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USDA	Carbon Cycle Research (ARS)	0.6	0.6	0.6
	Carbon Cycle Research (FS)	3.3	3.5	3.5
	Carbon Inventory and Analysis (FS)	1.1	1.1	1.1
	Carbon Management Research (FS)	1.6	1.9	1.9
	Regional and Sectoral Impacts of Climate Change (ARS)	1.0	0.9	0.9
U.S. Department of Agriculture CCRI Total		**7.6**	**8.0**	**8.0**
DOC	Competitive Research Program	34.1	45.7	45.8
Department of Commerce CCRI Total		**34.1**	**45.7**	**45.8**
DOE	Atmospheric Radiation Measurement Program	5.7	5.7	5.6
	CCRI Climate Modeling	14.3	12.2	12.2
	CCRI Carbon Cycle	3.1	2.9	2.9
	CCRI Integrated Assessment	4.8	3.0	3.0
Department of Energy CCRI Total		**27.9**	**23.8**	**23.7**
DOT	DOT-wide Climate Change Center	0.6	0.7	0.7
Department of Transportation CCRI Total		**0.6**	**0.7**	**0.7**
USAID	Famine Early Warning System Network (FEWS NET)	13.0	14.0	13.0
U.S. Agency for International Development CCRI Total		**13.0**	**14.0**	**13.0**
NASA Science	Atmospheric Composition	2.4	2.6	2.7
	Climate Variability	4.6	4.8	4.9
	Carbon Cycle	6.3	6.5	6.6
	Water Cycle	6.2	6.4	6.4
	Terrestrial and Marine Ecosystems	1.9	2.1	2.2
	Land-Cover/Land-Use Change	0.9	1.1	1.2
	Human Contributions and Responses[1]	16.1	11.6	11.4
NASA Space	Atmospheric Composition	28.3	46.8	20.1
	Climate Variability	28.3	46.8	20.1
National Aeronautics and Space Administration CCRI Total[2]		**95.0**	**128.7**	**75.6**
NSF	Carbon Fluxes and Cycle	10.0	10.0	10.0
	Human Dimensions of Climate Change	5.0	5.0	5.0
	Modeling Strategy	10.0	10.0	10.0
National Science Foundation CCRI Total		**25.0**	**25.0**	**25.0**
Total Climate Change Research Initiative[3]		**203.2**	**245.9**	
President's Request				**191.8**

[1] Prior to FY 2007, NASA linked the Applied Sciences and the Education and Outreach programs to USGCRP Focus Areas, but not to CCSP research elements; the current table identifies these programs as contributing to the CCSP Human Contributions and Responses element for the three fiscal years addressed.

[2] NASA has revised the set of projects it counts as supporting CCRI. The funding levels presented include activities that were previously not counted, including portions of the High-End Computing and Scientific Computing projects. The funding decrease from 2007 to 2008 is primarily due to the planned ramp-down of resources for the Glory mission, a major contributor to NASA CCRI funding, which is completing development in preparation for a December 2008 launch.

[3] Activities in the Federal Aviation Administration – Research, Engineering, and Development account have been included under CCRI in past. Due to changes in CCSP/CCRI activities and priorities and changes within DOT, these activities are no longer considered part of CCRI.

Note: Any minor discrepancies within this table and between this table and others are due to rounding.

U.S. DEPARTMENT OF AGRICULTURE

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Global Carbon Cycle	**10.3**	**10.2**	**11.2**
Agricultural Research Service	2.6	2.4	1.8
Cooperative State Research, Education, and Extension Service	0.4	0.4	2.0
Economic Research Service	0.1	0.1	0.1
Forest Service	7.2	7.3	7.3
Water Cycle	**5.4**	**5.3**	**4.9**
Agricultural Research Service	4.0	3.8	3.4
Forest Service	1.4	1.5	1.5
Land-Use / Land-Cover Change	**1.3**	**1.3**	**0.1**
Cooperative State Research, Education, and Extension Service	1.3	1.3	0.1
Understanding Atmospheric Composition and Chemistry	**18.3**	**17.2**	**15.9**
Agricultural Research Service	18.3	17.2	15.9
Understanding Ecosystems Changes	**15.5**	**14.9**	**14.5**
Agricultural Research Service	11.8	11.1	10.4
Cooperative State Research, Education, and Extension Service	0.2	0.2	0.5
Forest Service	3.5	3.6	3.6
Support the UV-B Monitoring Network	**2.4**	**2.4**	**2.4**
Cooperative State Research, Education, and Extension Service	2.4	2.4	2.4
Other National Research Initiative	**0.2**	**0.1**	**0.4**
Cooperative State Research, Education, and Extension Service	0.2	0.1	0.4
USGCRP TOTAL	**53.4**	**51.4**	**49.4**
CCRI			
Carbon Cycle Research (ARS)	0.6	0.6	0.6
Carbon Cycle Research (FS)	3.3	3.5	3.5
Carbon Inventory and Analysis (FS)	1.1	1.1	1.1
Carbon Management Research (FS)	1.6	1.9	1.9
Regional and Sectoral Impacts of Climate Change (ARS)	1.0	0.9	0.9
CCRI TOTAL	**7.6**	**8.0**	**8.0**
Department of Agriculture Total	**61.0**	**59.4**	
President's Request			**57.4**

Mapping of Budget Request to Appropriations Legislation. In the interim Appropriations acts, Department of Agriculture CCSP activities are funded under Title I–Agricultural Programs, within the ARS, CSREES Research and Education Activities, and ERS accounts; and under Title II–Conservation Programs, within the NRCS Conservation Operations account. In the interim Appropriations acts, U.S. Department of Agriculture CCSP activities are funded in the USDA FS section under Title II–Related Agencies, within the FS Forest Research account.

DEPARTMENT OF COMMERCE

DOC	Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
	USGCRP			
NOAA	Laboratories and Cooperative Institutes	45.8	42.6	42.7
NOAA	Competitive Research Program	70.6	70.6	86.5
NOAA	Climate Data and Information	2.4	4.4	8.2
NOAA	Climate Operations	0.4	0.9	0.9
NOAA	Climate Regimes and Ecosystem Productivity	1.5	1.5	2.0
NOAA	Operational Climate Programs	80.1	70.1	53.7
NIST	Measurements and Standards for the CCSP	0.0	0.0	5.0
USGCRP TOTAL		**200.9**	**190.0**	**199.0**
	CCRI			
NOAA	Competitive Research Program	34.1	45.7	45.8
CCRI TOTAL		**34.1**	**45.7**	**45.8**
Department of Commerce Total President's Request		**235.0**	**235.7**	**244.8**

Notes:
1) Starting in FY 2006, funding to DOC/NOAA's Laboratories was included as part of DOC/NOAA CCSP activities. This is a result of the evolution of NOAA's role in CCSP.
2) DOC/NOAA previously reported its climate research activities under its Office of Oceanic and Atmospheric Research (OAR) line office and the National Marine Fisheries Service (NMFS) line office. For FY 2008, NOAA made a decision to report activities for the NOAA climate strategic goal, as defined in the NOAA Strategic Plan (2005), to ensure consistent reporting and provide the most accurate picture of its climate funding to date. The climate goal includes both research and operations funding under the following offices: OAR, NMFS, the National Weather Service, and the National Environmental Satellite, Data, and Information Service.
3) Past reports have erroneously presented all of DOC/NOAA's CCSP funding in the Operations, Research, and Facilities (ORF) account. Climate-related activities have been and continue to be funded in both the ORF account and the Procurement, Acquisition, and Construction (PAC) account.
4) In FY 2008, DOC includes funding for new measurement and standards-related activities that DOC/NIST will undertake to support CCSP.

Mapping of Budget Request to Appropriations Legislation. In Appropriations Committee reports, funding for National Oceanic and Atmospheric Administration CCSP activities is specified in the Laboratories and Cooperative Institutes, Competitive Research Programs, Climate Operations, and Climate Data and Information lines of the Oceanic and Atmospheric Research budget; in the Climate Regimes and Ecosystem Productivity line of the National Marine Fisheries Service budget; the Data Centers and Information Services line of the National Environmental Satellite, Data, and Information Service (NESDIS) budget; and the Local Warnings and Forecasts and Central Forecast Guidance lines of the National Weather Service (NWS) budget within NOAA's Operations, Research, and Facilities account. In addition, a portion of NOAA's climate funding is found within the Procurement, Acquisition, and Construction account for NESDIS and NWS. Funding for National Institute of Standards and Technology CCSP activities is specified in the Scientific and Technical Research and Services account.

DEPARTMENT OF ENERGY

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Climate Change Modeling	12.7	13.0	20.3
Climate Forcing	67.6	69.2	69.3
Climate Change Response	22.1	20.2	16.4
USGCRP TOTAL	**102.4**	**102.4**	**106.0**
CCRI			
Atmospheric Radiation Measurement Program	5.7	5.7	5.6
Climate Modeling	14.3	12.2	12.2
Carbon Cycle	3.1	2.9	2.9
Integrated Assessment Research	4.8	3.0	3.0
CCRI TOTAL	**27.9**	**23.8**	**23.7**
Department of Energy Total President's Request	**130.3**	**126.2**	**129.7**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, Department of Energy CCSP activities are funded under Title III–Department of Energy, within the Energy Supply, Research, and Development Activities account. Also in these Appropriations Committee reports, funding for Department of Energy CCSP activities is included as part of the appropriation for Biological and Environmental Research.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

HHS	Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
	USGCRP			
NCI	Health Effects of UV Radiation	36.0	36.0	35.0
NIEHS	Human Health Effects of Exposure	13.0	13.0	13.0
NIAMS	Health Effects of UV Radiation	1.0	1.0	1.0
USGCRP TOTAL		**50.0**	**50.0**	**49.0**
Department of Health and Human Services Total		**50.0**	**50.0**	
President's Request				**49.0**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, Department of Health and Human Services CCSP activities are funded under the National Institutes of Health section of Title II–Department of Health and Human Services.

DEPARTMENT OF THE INTERIOR

DOI	Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
	USGCRP			
USGS	Earth Surface Dynamics	4.5	4.4	4.4
USGS	Global Change Hydrology (Hydroclimatology)	5.0	5.4	5.4
USGS	Land Characterization Research and Applications	5.6	5.4	5.4
USGS	Satellite Data Management and Dissemination	6.9	6.6	6.6
USGS	Terrestrial and Coastal Ecosystem Changes	0.3	0.3	0.3
USGS	Water Energy and Biogeochemical Budgets (WEBB)	4.5	4.3	4.3
USGCRP TOTAL		**26.8**	**26.4**	**26.4**
Department of the Interior Total		**26.8**	**26.4**	
President's Request				**26.4**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, Department of the Interior CCSP activities are funded under Title I–Department of the Interior. Funding for U.S. Geological Survey CCSP programs is included within the USGS Survey, Investigations, and Research account.

DEPARTMENT OF TRANSPORTATION

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Partnership for Air Transportation Noise and Emissions Reduction (PARTNER)	0.3	0.3	0.5
USGCRP TOTAL	**0.3**	**0.3**	**0.5**
CCRI			
DOT-wide Climate Change Center	0.6	0.7	0.7
CCRI TOTAL	**0.6**	**0.7**	**0.7**
Department of Transportation Total	**0.9**	**1.0**	
President's Request			**1.2**

Notes:
1) The 2006 and 2007 funding for Federal Highway Administration – Federal-Aid Highways was less than $500,000.
2) The 2006 and 2007 funding for Federal Aviation Administration – Research, Engineering, and Development was less than $500,000.
3) Federal Transit Administration - Research and University Research Centers is FTA's support for DOT's Center for Climate Change. This program has been provided funding in the past; however, it was not reported because funding has been less than $500,000.
4) Activities in the Federal Aviation Administration – Research, Engineering, and Development account have been included under CCRI in past. Due to changes in CCSP/CCRI activities and priorities and changes within DOT, these activities are no longer considered part of CCRI.

Mapping of Budget Request to Appropriations Legislation. Since 2000, the Department's climate change research has been funded by contributions from eight of DOT's operating administrations and the Office of the Secretary.

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
CCRI			
Famine Early Warning System Network (FEWS NET)	13.0	14.0	13.0
CCRI TOTAL	**13.0**	**14.0**	**13.0**
U.S. Agency for International Development Total	**13.0**	**14.0**	
President's Request			**13.0**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, U.S. Agency for International Development CCSP activities are funded under Title II–Bilateral Economic Assistance: United States Agency for International Development.

ENVIRONMENTAL PROTECTION AGENCY

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Air Quality Research and Assessment	7.2	5.9	6.2
Ecosystem Research and Assessment	6.1	4.0	4.4
Human Health Research and Assessment	0.2	1.5	1.6
Water Quality Research and Assessment	0.4	0.3	0.5
Research and Assessments of the Integrated Effects of Global Change	4.7	4.5	4.2
USGCRP TOTAL	**18.6**	**16.2**	**16.9**
Environmental Protection Agency Total	**18.6**	**16.2**	
President's Request			**16.9**

Note:
1) Entries given in FY 2006 and FY 2007 for EPA are "enacted" budgetary amounts.

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, Environmental Protection Agency CCSP activities are funded under the EPA section of Title III–Independent Agencies, within the Science and Technology account. Appropriations Committee report language may specify more directly the funding for global change research.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Atmospheric Composition	85.1	79.9	77.0
Climate Variability	85.4	80.6	83.4
Carbon Cycle	50.6	46.2	48.9
Water Cycle	94.4	93.9	92.9
Ecosystems	45.3	39.7	40.1
Land-Cover / Land-Use Change	22.0	20.3	19.7
Human Contributions and Responses	38.8	28.4	28.1
USGCRP Scientific Research Sub-Total	**421.6**	**389.0**	**390.1**
Atmospheric Composition	51.6	48.9	50.7
Climate Variability	137.3	183.9	168.8
Carbon Cycle	84.0	141.3	119.3
Water Cycle	96.5	106.8	174.5
Ecosystems	36.1	41.4	47.4
Land-Cover / Land-Use Change	30.3	43.0	57.7
USGCRP Space-Based Observations Sub-Total	**435.8**	**565.3**	**618.4**
USGCRP TOTAL	**857.4**	**954.3**	**1,008.5**
CCRI			
Atmospheric Composition	2.4	2.6	2.7
Climate Variability	4.6	4.8	4.9
Carbon Cycle	6.3	6.5	6.6
Water Cycle	6.2	6.4	6.4
Ecosystems	1.9	2.1	2.2
Land-Cover / Land-Use Change	0.9	1.1	1.2
Human Contributions and Responses	16.1	11.6	11.4
CCRI Scientific Research Sub-Total	**38.4**	**35.1**	**35.4**
Atmospheric Composition	28.3	46.8	20.1
Climate Variability	28.3	46.8	20.1
CCRI Space-Based Observations Sub-Total	**56.6**	**93.6**	**40.2**
CCRI TOTAL	**95.0**	**128.7**	**75.6**
National Aeronautics and Space Administration Total	**952.4**	**1,083.0**	
President's Request			**1,084.1**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, National Aeronautics and Space Administration CCSP activities are funded under NASA Earth science and technology programs within Title III–Independent Agencies, as part of the Science, Aeronautics, and Technology account.

NASA Notes:

1) NASA has revised the set of programs and projects it counts as supporting CCSP goals. Beginning in FY 2006, the funding levels presented do not include the Ground Network and Research Range assets or Congressional interest items but do include activities not previously counted such as the NPOESS Preparatory Project, portions (33%) of the Landsat Data Continuity Mission (LDCM), and the Gravity Recovery and Climate Experiment (GRACE), as well as portions of the High-End Computing and Scientific Computing projects.
2) NASA has also revised the set of projects it counts as supporting CCRI. The funding levels presented include activities that were previously not counted, including portions of the High-End Computing and Scientific Computing projects. The funding decrease from 2007 to 2008 is primarily due to the planned ramp-down of resources for the Glory mission, a major contributor to NASA CCRI funding, which is completing development in preparation for a December 2008 launch.
3) Prior to FY 2007, NASA linked the Applied Sciences and the Education and Outreach programs to USGCRP Focus Areas, but not to CCSP research elements; the current table identifies these programs as contributing to the CCSP Human Contributions and Responses element for the three fiscal years addressed.

NATIONAL SCIENCE FOUNDATION

Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
USGCRP			
Atmospheric Composition	19.5	20.7	20.7
Climate Variability and Change	74.3	78.4	79.4
Carbon Cycle	25.0	30.2	31.2
Water Cycle	18.0	16.4	17.4
Terrestrial and Marine Ecosystems	21.1	20.5	20.5
Land Use / Land Cover	2.8	2.8	2.8
Human Dimensions of Climate Change	11.2	11.2	11.2
USGCRP TOTAL	**171.9**	**180.2**	**183.2**
CCRI			
Carbon Fluxes and Cycle	10.0	10.0	10.0
Human Dimensions of Climate Change	5.0	5.0	5.0
Modeling Strategy	10.0	10.0	10.0
CCRI TOTAL	**25.0**	**25.0**	**25.0**
National Science Foundation Total President's Request	**196.9**	**205.2**	**208.2**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, National Science Foundation CCSP activities are supported under the NSF section of Title III–Independent Agencies within the NSF Research and Related Expenses account.

SMITHSONIAN INSTITUTION

SI	Program Title	FY 2006	FY 2007 Estimate	FY 2008 Request
	USGCRP			
NMNH	Archaebiology Program (Human Ecology History)	0.3	0.3	0.3
NMNH	Paleoecological Effects of Climate Change, including Evolution of Terrestrial Ecosystems	0.9	0.9	0.9
NMNH	Global Volcanism Program	0.2	0.2	0.2
NMNH	Human Origins Program (Human Ecological History)	0.3	0.3	0.3
NMNH	Nile Delta Subsidences / Sea-Level Rise	0.2	0.2	0.2
NMNH	Tropical Biodiversity Program	0.6	0.6	0.6
SERC	Ecological Effects of Ultraviolet Radiation	0.2	0.2	0.2
SERC	Effects of Increasing Atmospheric CO_2 on Ecosystems	0.3	0.3	0.3
STRI	Temperate and Tropical Forest Canopy Biology	0.4	0.4	0.4
STRI	Tropical Forest Science	0.9	0.9	0.9
STRI	Biodynamics of Forest Fragments	0.1	0.1	0.1
STRI	Tropical Agroforestry	0.2	0.2	0.2
NZP	Migratory Birds	0.3	0.3	0.3
NZP	Predicting Species Responses	0.7	0.7	0.7
MAB	Monitoring and Assessment of Biodiversity (MAB) Program	0.1	0.1	0.1
USGCRP TOTAL		**5.7**	**5.7**	**5.7**
Smithsonian Institution Total		**5.7**	**5.7**	
President's Request				**5.7**

Mapping of Budget Request to Appropriations Legislation. In the Appropriations Committee reports, Smithsonian Institution CCSP activities are funded in the Smithsonian section of Title II–Related Agencies, within the Salaries and Expenses account. Appropriations Committee reports specify funding for a Sciences line item component of this account, which includes CCSP programs.

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CONTACT INFORMATION

Climate Change Science Program Office
1717 Pennsylvania Avenue, NW
Suite 250
Washington, DC 20006
202-223-6262 (voice)
202-223-3065 (fax)
information@climatescience.gov
information@usgcrp.gov
http://www.climatescience.gov/
http://www.usgcrp.gov/

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U.S. Climate Change Science Program
1717 Pennsylvania Avenue, NW • Suite 250 • Washington, D.C. 20006 USA
+1.202.223.6262 (voice) • +1.202.223.3065 (fax)
http://www.climatescience.gov/